National Transmission Network Development Plan

December 2018

For the National Electricity Market

Important notice

PURPOSE

The Australian Energy Market Operator (AEMO) publishes the 2018 National Transmission Network Development Plan under section 49 of the National Electricity Law and clause 5.20 of the National Electricity Rules.

This publication has been prepared by AEMO using information available at 16 November 2018. Information made available after this date may have been included in this publication where practical.

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VERSION CONTROL

Version	Release date	Changes
1.0	21/12/2018	Release

Executive summary

In June 2018, AEMO published the first Integrated System Plan (ISP) [1], which met the requirements of a National Transmission Network Development Plan (NTNDP) and provided a strategic plan for the development of the power system. The 2018 NTNDP builds on the ISP, assesses the short-term system adequacy of the national transmission grid over the next five years and reports on the implementation of the ISP.

Prudent network investment is crucial for an affordable, reliable, and sustainable power system

The ISP provided the blueprint for smoothly managing the transition of the power system over the coming 20 years. It identified the portfolio of resources needed for the future, and the prudent transmission network investments needed to securely connect consumers with the new generation and energy storage and deliver customers' needs at the lowest possible resource cost. It demonstrated the changing role of transmission, no longer simply to provide bulk energy transport from remote generation to load centres, but a more strategic one with multiple value streams that will enable competitive sharing of resources across regions, and allow the market to deliver the technological requirements for the evolving power system.

The nature of the changes underway in the power system means that an integrated approach is needed to address the essential technical engineering requirements by which the power system operates. These technical requirements include voltage control, frequency management, harmonics, inertia, system strength, fault levels, system restart, and oscillatory and transient stability as well as thermal loading. The ISP provided such a strategic blueprint.

The ISP presented a strategic development plan for resources and transmission, with identified transmission network investments integrated with the proposed development of the identified resource development needs. The ISP recommended staged network upgrades, progressively developing the network as the needs arise and aligned with the development of resources needed.

The ISP was published in June 2018 and remains current. It is key that projects identified in Group 1 in the ISP are implemented as soon as possible and that Group 2 projects are refined through further analysis and progressed in a timely manner.

Development updates

The ISP relies on the existing regulatory framework for transmission planning, which requires that each jurisdictional Transmission Network Service Provider (TNSP) apply the Regulatory Investment Test for Transmission (RIT-T) to obtain revenue approval from the AER for any regulated transmission investment above $6 million. Each TNSP has commenced the regulatory processes for each Group 1 project.

The projects identified in Group 1 of the ISP are all progressing, but current timing for implementation of many of the projects in Group 1 of the ISP are at risk of not meeting their deadlines for completion without further action:

- The South Australia system strength remediation project addresses a fault level shortfall in South Australia and takes advantage of recent changes to expedite the approvals process for urgent system strength requirements. As a result, it is currently progressing towards implementation as soon as reasonably practical. In the meantime, the requirement that this project will address is being managed operationally, including use of directions by AEMO if needed to maintain power system security.

[1] AEMO. *2018 Integrated System Plan*, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/ISP/2018/Integrated-System-Plan-2018_final.pdf

- The Queensland to New South Wales interconnector upgrade is unlikely to be completed prior to 2023 if the full process for regulatory approvals, procurement, and planning approvals is undertaken, which could then impact reliability in New South Wales following the Liddell Power Station closure. The Queensland to New South Wales minor upgrade could be brought forward and potentially completed by late 2021 if the detailed design and procurement were to be carried out in parallel with the regulatory approvals processes, which would require the costs of such studies and commitments to be underwritten to recover costs should the investments not go ahead, and the revenue determination by the AER and approval of contingent projects were finalised to permit finalisation of investment decisions.
- The Victoria to New South Wales interconnector upgrade project is expected just before closure of Liddell Power Station in late 2022. Any delays to the project could impact reliability in New South Wales following the Liddell Power Station closure.
- The regulatory, design and procurement processes for the proposed transmission augmentation in Western and North Western Victoria is well progressed. There remains a high risk of curtailment of renewable generation that is connecting or connected in this area, as practical implementation is now expected in 2024-25 due to the extent of works required.

AEMO notes the work by the Energy Security Board (ESB) to develop an approach to deliver Group 1 projects as soon as possible including rule changes to streamline regulatory processes. The approach proposed by the ESB was agreed by the Council of Australian Governments (COAG) Energy Council at their December meeting and deals with a number of these risks.

Short-term system adequacy

As the transformation of the power system continues, new challenges raised for the power system are requiring new engineering solutions to address system security and system adequacy. A key role of the NTNDP is to assess the short-term adequacy of the power system and identify any relevant system services shortfalls.

This NTNDP highlights the following areas for urgent action:

- Operation in New South Wales after closure of Liddell Power Station – following the power station's closure, without further developments the supply-demand balance could be very tight in New South Wales during periods of maximum demand, with a heightened risk of a reliability shortfall in New South Wales. It will be crucial that the interconnector upgrades from Queensland and Victoria are delivered in a timely manner, and that new local firm generating capacity is developed prior to the Liddell Power Station closure. Additional strategies such as encouraging and supporting new firm generator connections, greater use of DER, and demand management will help meet this emerging reliability shortfall. Prudent investment is also needed in the network to connect renewable resources within New South Wales, or the shortfalls could be larger. In addition, investments will be needed in reactive support for both maximum and minimum demand conditions.
- System strength and inertia shortfalls in South Australia – system strength and inertia are measures used to determine the stability of a power system under reasonable operating conditions. AEMO has defined the minimum levels of system strength[2] and inertia[3] for each NEM region:
  - The fault level shortfall declared in South Australia[4] will remain until new high-inertia synchronous condensers are installed by ElectraNet to address the system strength need[5].

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[2] *System Strength Requirements* - AEMO, available at http://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/System_Strength_Requirements_Methodology_PUBLISHED.pdf

[3] *Inertia Requirements* - AEMO, available at http://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/Inertia_Requirements_Methodology_PUBLISHED.pdf

[4] *Second Update to the 2016 NTNDP* - AEMO, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NTNDP/2017/Second_Update_to_the_2016_NTNDP.pdf

[5] ElectraNet. Strengthening South Australia's Power System, available at https://www.electranet.com.au/what-we-do/projects/power-system-strength/.

- AEMO now declares an inertia shortfall in South Australia. AEMO recommends that ElectraNet fit flywheels to the proposed synchronous condensers and consider opportunities for developments that provide fast frequency response (FFR).

- Voltage control in South Australia and Victoria during minimum demand – the issues with high voltages occurring during minimum demand periods are expected to worsen and necessitate remedial actions. The current operational strategy of de-energising lines to manage voltages is a last-resort measure that is undesirable in normal practice, because it reduces system resilience and can lead to reliability risks.
  - In South Australia, the synchronous condensers that ElectraNet is planning to install will assist with voltage control.
  - In Victoria, AEMO has commenced the regulatory approvals process for "Victorian reactive power support"[6] to address voltage control requirements in the long term. In the interim, AEMO is investigating other minor augmentations and contractual arrangements to meet operational needs.
- Credible contingencies affecting multiple generating units – with the introduction of large quantities of new generation widely dispersed across new areas in the network, new contingencies are emerging in the power system. There are increasing instances where multiple generating units could now potentially be affected by a single credible contingency, resulting in their disconnection or requiring runback. These contingencies can represent a significant loss of generation, impacting stability, ancillary services, and reserve management. New constraint equations may be needed to ensure the network continues to operate in a secure state – possibly leading to further congestion and curtailment of renewable generation.

[6] AEMO. *Victorian reactive power support, RIT-T Project Specification Consultation Report*, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/Victorian_Transmission/2018/Victorian-reactive-power-support-RIT-T-PSCR.pdf.

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1. About the NTNDP

The 2018 NTNDP includes AEMO's 2018 ISP[7], and provides an update to short-term system adequacy of the national transmission grid over the next five years. The longer-term implementation of the 2018 ISP is also presented. AEMO publishes the 2018 National Transmission Network Development Plan under section 49 of the National Electricity Law and clause 5.20 of the National Electricity Rules.

As the ISP delivered the NTNDP requirements, the 2018 NTNDP is a succinct document that includes outcomes from the ISP and other material to meet the requirements of an NTNDP, including AEMO's 2018 Electricity Statement of Opportunities (ESOO)[8], the latest annual planning reports (released in mid-2018) provided by TNSPs, an up to date assessment of Network Support and Control Ancillary Services (NSCAS) needs, and declares relevant system services shortfalls.

The 2018 NTNDP includes:

- Reports on transmission and resource developments, including projects identified in the ISP (section 2).
- Assessment of impacts of delayed development of Renewable Energy Zones (REZs) and interconnectors.
- Updated assessment of the short-term power system adequacy of the NEM to determine whether NSCAS are required in the next five years (Section 3, and Appendix A).
- Identification of minimum inertia shortfalls for individual regions (Section 3).

The following information is provided on AEMO's website to form the NTNDP database:

- 2018 ISP, which gives an overview of the modelling, results and proposed development plan[9].
- 2018 ISP Appendices, which includes more details of the modelling and consultation AEMO completed[10].
- 2018 ISP Database, which provides supporting modelling data and input assumptions[11].
- 2018 Transmission Annual Planning Report (TAPR) summaries for each TNSP[12].
- Generator Information Pages, which summarise the current and future generation in each region[13].
- Interactive map – visual presentation of the ISP outcomes[14].
- 2017 Network Flows and Congestion data[15].

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[7] AEMO. *2018 ISP,* available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/ISP/2018/Integrated-System-Plan-2018_final.pdf. The 2018 ISP also satisfied AEMO's rule obligations for the 2017 NTNDP.

[8] AEMO. *2018 Electricity Statement of Opportunities*, available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/NEM-Electricity-Statement-of-Opportunities.

[9] AEMO. *2018 ISP,* available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/ISP/2018/Integrated-System-Plan-2018_final.pdf.

[10] AEMO. *2018 ISP Appendices*, available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Integrated-System-Plan.

[11] AEMO. *2018 ISP Database*, available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Integrated-System-Plan/ISP-database.

[12] AEMO. *2018 NTNDP TAPR Summaries*, available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Transmission-Network-Development-Plan.

[13] AEMO. *Generation information page*, available at http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Generation-information

[14] AEMO. *Interactive maps and dashboards*, available at http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Interactive-maps-and-dashboards.

[15] AEMO publishes information on congestion within the Congestion Information Resource (CIR). The CIR provides a consolidated source of information about transmission network congestion (constraint) risk – including data, policies, guidelines, consultation and educational material. Available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Congestion-information.

2. Development updates

Key points

- Overview of the ISP – The ISP identified the optimal plan to facilitate a smooth transition of Australia's evolving power system over the coming 20 years. The ISP demonstrated that prudent transmission developments are a key enabler for the efficient development of resources needed for power system reliability and security. A development plan was presented in the ISP, with identified transmission network investments prioritised and fully integrated with the proposed development of the identified resource development needs.
- Implementing an integrated system-wide plan has been challenging – At the time of its release, there was no framework to directly implement a strategic blueprint with a system-wide integrated view, such as the ISP.
- Group 1 projects are being progressed to meet short-term system needs – Group 1 projects are all proceeding. Delays to these projects could result in a range of impacts, including potential reliability risks following the closure of Liddell Power Station in New South Wales.
- Group 2 and 3 projects are being refined – work is also progressing on many Group 2 and 3 projects. This work includes RIT-Ts in some cases, further work on design assessments, and investigations into resilience benefits that may result in projects being brought forward.

2.1 Overview of the ISP

A portfolio of diverse generation and storage supported by prudent transmission investment

The ISP provided the blueprint for smoothly managing the transition of the power system over the coming 20 years. It identified the portfolio of resources and the prudent transmission network investments needed to meet customers' needs reliably, securely and at the lowest resource cost.

The nature of the changes underway in the power system means that an integrated approach is needed to address the essential technical engineering requirements by which the power system operates. These technical requirements include voltage control, frequency management, harmonics, inertia, system strength, fault levels, system restart, and oscillatory and transient stability as well as thermal loading. The ISP provided such a strategic blueprint.

The ISP demonstrated that:

- Establishment of REZs can provide an efficient way to integrate new generation – Considering the benefits in economies of scale, the ISP identified REZs where there are projected to be considerable benefits in upgrading the network to facilitate connection of high-quality renewable resources. The ISP also recommended the optimal timing for these REZ developments in conjunction with other network investments, such as interconnector upgrades, to reduce overall cost.
- Acting too slowly can lead to higher costs – consumers may face higher electricity costs if action is taken too slowly. It is vital that the projected development of the resource portfolio proceed in a timely manner, and the requisite network development to support this also proceed in a timely manner. Delays to upgrades of the transmission system are already forcing new generators to connect in locations with lower quality resources and increasing periods where existing generators are forced to curtail their output. This could potentially result in higher wholesale market prices in the short term. If alternative investments are urgently needed to address the short-term gaps created by delays, this may limit the most efficient

ways to progress longer-term solutions, impacting resilience and increasing operating costs of the NEM in the long term as less efficient engineering solutions are forced in because of delays.

- Strategically increasing interconnection is the most efficient way forward – the ISP analysis demonstrated that there would be significant benefits across all scenarios to strategically increasing interconnection, and the development plan is built around implementing this strategy. This approach is expected to put downward pressure on electricity bills by increasing competition across the NEM.

The ISP presented a strategic development plan for resources and transmission, with identified transmission network investments integrated with the proposed development of the identified resource development needs. By staging the recommended network upgrades progressively in step with the development of the resource portfolio needed to manage this transition, the ISP minimises the risk of overinvestment in the network, while providing a roadmap of the strategic decision points for investments needed. Each element in this plan forms part of the larger strategic picture, providing more value and benefits as a well-designed cohesive integration than simply as a collective of coordinated individual projects.

As a result, the projects were split into three groups with matching needs:

- Group 1 projects are needed to meet short-term system needs – these projects are suited to immediate action that will minimise costs and help address potential reliability shortfalls.
- Group 2 projects are needed to enhance trade, access storage, and support REZ development – these projects are larger in scale and more involved than those in Group 1. Further analysis will be undertaken to refine the detailed design and timing of these projects. Detailed design and easement selection will be complex and may take several years. Work on these projects needs to be advanced so that these projects will be ready when they are needed.
- Group 3 projects are needed to support long-term REZ development and system reliability and security – these projects are designed to support wide-spread development of renewable resources, storage and DER to replace retiring conventional generators.

The projects identified in Group 1 were:

- South Australia system strength – to remedy system strength in South Australia, reducing the need for market intervention and supporting renewable energy development.
- Queensland to New South Wales upgrade – to support reliability in New South Wales following the closure of Liddell Power Station, and to export renewable generation.
- Victoria to New South Wales upgrade – to support reliability in New South Wales following the closure of Liddell Power Station, and to export renewable generation.
- Western Victoria Renewable Integration – to support the efficient delivery of new generation in western Victoria and north-western Victoria.

2.2 Status of developments

A review of the current limitations on NEM interconnectors and the developments considered in the ISP is detailed in Appendix A2.

The ISP relies on the existing regulatory framework for transmission planning, which requires that each jurisdictional TNSP apply the RIT-T to obtain revenue approval from the AER for any regulated transmission investment above $6 million. Each TNSP has commenced the regulatory processes for each Group 1 project.

Group 1 projects

- The South Australia system strength remediation project addresses a fault level shortfall in South Australia and takes advantage of recent changes to expedite the approvals process for urgent system strength requirements. As a result, it is currently progressing towards implementation as soon as reasonably practical. The requirement that this project will address is currently being managed operationally, including use of directions by AEMO if needed to maintain power system security.

- The other Group 1 projects will be delivered later than the times when the ISP identified would be optimal, based on delivering net market benefits by avoiding more expensive generation that would be otherwise required to meet reliability and security. This later timing is only partly due to the regulatory processes for new transmission investment. It is also partly due to the time it takes for implementation itself, including planning approvals, easement acquisition, procurement and manufacturing, and commissioning and testing. This demonstrates the need to plan well and take prudent action in a timely fashion.

The current timing for implementation of many of the projects in Group 1 are at risk of not meeting their deadlines for completion without further action:

- In New South Wales, existing and currently committed generation projects are not sufficient to meet reliability standards following the closure of Liddell Power Station. It is vital that the projected development of the resource portfolio proceed in a timely manner, along with the development of the network required to support it.
- The Queensland to New South Wales interconnector upgrade[16] is unlikely to be completed prior to 2023 if the full process for regulatory approvals, procurement, and planning approvals is undertaken, which could then impact reliability in New South Wales following the Liddell Power Station closure. This timing is likely to impact reliability in New South Wales following closure of the Liddell Power Station in late 2022. The Queensland to New South Wales minor upgrade could be brought forward and potentially completed by late 2021 if the detailed design and procurement were to be carried out in parallel with the regulatory approvals processes, which would require the costs of such studies and commitments to be underwritten to recover costs should the investments not go ahead, and the revenue determination by the AER and approval of contingent projects were finalised to permit finalisation of investment decisions.
- The Victoria to New South Wales interconnector upgrade project[17] is expected just before closure of Liddell Power Station in late 2022. The critical path developments involve procurement, installation, commissioning, and testing of a new 500/330 kV transformer and associated infrastructure. Any delays to the project could impact reliability in New South Wales following the Liddell Power Station closure.
- The regulatory, design and procurement processes for the proposed transmission augmentation in Western and North Western Victoria[18] are well progressed. There remains a high risk of curtailment of renewable generation that is connecting or connected in this area, as practical implementation is now expected in 2024-25 due to the extent of works required. The timeline to implement the Western Victoria Renewable Integration project could vary further than indicated, depending on the final options selected for implementation and community feedback.

The ESB has developed an approach to expedite the delivery of Group 1 projects in consultation with stakeholders and the energy institutions. The proposed approach requires rule changes to streamline regulatory processes and seeks jurisdictions support to facilitate planning approvals. The approach proposed by the ESB was agreed by the COAG Energy Council at their December meeting and will support the timely implementation of projects in Group 1.

Group 2 and Group 3 projects

The developments in Group 2 and 3 are larger in scale and cost than those in Group 1. Some of the projects are needed soon after the completion of the Group 1 projects. Detailed design assessment for these projects is already underway and AEMO plans to undertake further modelling and analysis to refine the plan. The

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[16] Powerlink & TransGrid. Expanding New South Wales Queensland Transmission Transfer Capacity, available at https://www.powerlink.com.au/sites/default/files/2018-11/Project%20Specification%20Consultation%20Report%20-%20Expanding%20NSW%20Qld%20Transmission%20Transfer%20Capacity%20-%20Overview%20Document.pdf.

[17] AEMO & TransGrid. *Victoria to New South Wales Interconnector Upgrade RIT-T*, available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Victorian-transmission-network-service-provider-role/Regulatory-investment-tests-for-transmission.

[18] AEMO. *Western Victoria Renewable Integration – Project Assessment Draft Report*, available at: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/Victorian_Transmission/2018/Western-Victoria-Renewable-Integration-RIT-T-PADR.PDF.

exact timing of each project also needs refinement and will often depend on actual development of new renewable resources, power station closures, and commitments on other major project developments.

TNSPs have commenced the regulatory approval processes for several of the transmission development projects in Groups 2 and 3 (for example, the new South Australia to New South Wales interconnector, and the Battery of the Nation MarinusLink project). AEMO is also working closely with project proponents to refine and extend the modelling of the remainder of the projects to better understand the costs, benefits, and factors that affect these projects. A key area of exploration is to examine in more detail the resilience benefits that could be delivered by developing transmission or storage projects.

3. Short-term power system adequacy

Key short-term operational challenges

AEMO has identified the following short term operational challenges from its planning work and specific analysis undertaken for this NTNDP:

- Operations in New South Wales after Liddell Power Station closure – Transmission upgrades from Queensland and Victoria and firm generating capacity developments in New South Wales are needed to avoid the risk of a reliability shortfall during periods of maximum demand. Investments are also needed in reactive support for both maximum and minimum demand conditions, and, subject to further studies, there may be a need for investment to support minimum fault levels.
- System strength and inertia requirements – The availability of network locations with high system strength is quickly declining and will continue to do so without appropriate investment:
  - The current fault level shortfall in South Australia will continue until new high-inertia synchronous condensers are installed by ElectraNet to address the system strength need.
  - AEMO also declares an inertia shortfall in South Australia. AEMO recommends that ElectraNet fit flywheels to the proposed synchronous condensers and consider opportunities for developments that provide fast frequency response (FFR).
  - Low system strength in many other areas of the network will affect non-synchronous generation connections, potentially requiring existing non-synchronous generation to be heavily constrained during planned outages. New non-synchronous generator connections in weak areas of the grid are highly likely to be required to incorporate system strength remediation in their projects.
- Voltage control in South Australia and Victoria during minimum demand – Increasingly, managing high voltages during minimum demand periods is expected to require investment in reactive support.
  - In South Australia, the synchronous condensers that ElectraNet is planning to install will assist with voltage control.
  - In Victoria, AEMO has commenced the regulatory approvals process for "Victorian reactive power support"[19] to address voltage control requirements in the long term. In the interim, AEMO is investigating other minor augmentations and contractual arrangements to meet operational needs.
- Credible contingencies affecting multiple generating units – New contingencies are emerging in the power system with the introduction of large quantities of new generation widely dispersed across new areas in the network. There are increasing instances where multiple generating units could now potentially be affected by a credible contingency, resulting in their disconnection or requiring runback. These contingencies can represent a significant loss of generation, impacting stability, ancillary services and reserve management. New constraint equations may be needed to ensure the network continues to operate in a secure state – possibly leading to further congestion and curtailment of renewable generation in Western Victoria and South Western New South Wales.

[19] AEMO. *Victorian reactive power support, RIT-T Project Specification Consultation Report*, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/Victorian_Transmission/2018/Victorian-reactive-power-support-RIT-T-PSCR.pdf.

As the transformation of the power system continues, new challenges raised for the power system are requiring new engineering solutions to address system security and system adequacy. A key role of the NTNDP is to assess the short-term adequacy of the power system and identify any relevant system services shortfalls.

This NTNDP provides an up to date assessment of the short-term power system adequacy of the NEM to determine whether Network Support and Control Ancillary Services (NSCAS) are required in the next five years (refer also Appendix A) and identifies minimum inertia shortfalls for individual regions.

The major short-term challenges identified by this assessment are:

- Operations in New South Wales after the closure of Liddell Power Station in late 2022.
- System strength and inertia requirements.
- Voltage control during low demand periods.
- Credible contingencies affecting multiple generating units.

3.1 Closure of Liddell Power Station

The best advice available to AEMO indicates that Liddell will close late in 2022. Following the power station's closure, if there are no further developments then the supply-demand balance could be very tight in New South Wales during periods of maximum demand[20]. If nothing is done, there would be a heightened risk of a reliability shortfall in New South Wales during these periods. It will be crucial that the interconnector upgrades from Queensland and Victoria delivered in a timely manner, and that new local firm generating capacity is developed[21] prior to the Liddell Power Station closure. Additional strategies such as encouraging and supporting new firm generator connections[22], greater use of DER, and demand management will help meet this emerging reliability shortfall. Prudent investment is also needed in the network to connect renewable resources within New South Wales, or the shortfalls could be larger. In addition, investments will be needed in reactive support for both maximum and minimum demand conditions, and, subject to further studies, there may be a need for further investment to support minimum fault levels.

In the absence of the requisite investments identified in the ISP, the closure of Liddell Power Station in 2022 is projected to adversely affect the New South Wales grid in relation to:

- Reliability at times of maximum demand.
- Reactive power during maximum demand.
- High voltage at times of minimum demand.
- System strength.

3.1.1 Managing supply during maximum demand conditions

The Liddell Power Station closure will withdraw up to 2,000 MW of firm[23] generating capacity from the New South Wales system in 2022-23. The 2018 ESOO projected that, without the resource and network developments identified in the ISP, reliability gaps would emerge in New South Wales after the retirement of

[20] AEMO. *2018 ESOO*, available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/NEM-Electricity-Statement-of-Opportunities.

[21] The NSW government has committed $55 million funding to its Emerging Energy Program, available at https://www.energy.gov.au/news-media/news/emerging-energy-program-nsw-business

[22] The NSW government has committed $55 million funding to its Emerging Energy Program, available at https://www.energy.gov.au/news-media/news/emerging-energy-program-nsw-business.

[23] Firm capacity can be dispatched to maintain balance on the power grid. It can include generation on the grid, storage, demand resources behind the meter, flexible demand, or flexible network capability.

Liddell Power Station, and would increase year-on-year to the end of the 10-year outlook as maximum demand grows[24]:

- Without further development as identified in the ISP (including resource and supporting transmission development), the reliability standard is forecast to not be met in the Neutral scenario by 2023-24, in the Fast change scenario by 2022-23 and in the Slow change scenario by 2026-27.
- In the absence of further development, a reliability gap of 150 MW is projected from 2023-24, increasing to up to 700 MW by 2027-28, with reliability most at risk in summer between 4.00 pm and 7.00 pm.
- The reliability risk is projected to be highest when New South Wales is experiencing maximum demand at the same time as either Queensland or Victoria.

The ESOO projections only include current and committed projects, showing what would happen if no further resource and network development occurs. The results of the ESOO reinforce the urgency of implementing the new generation and network upgrades that are outlined in the ISP.

The development of resources to provide additional dispatchable capacity and the associated transmission network identified in the ISP as part of the integrated development plan is expected to reduce the level of projected unserved energy to within the reliability standard.

In response to the emerging risks, the New South Wales Government has announced an Emerging Energy Program[25] and its Transmission Infrastructure Strategy[26]. The Strategy forms part of the government's broader plan for transition of its energy system, including supporting increased interconnection with Victoria, South Australia, and Queensland, accessing the Snowy Hydro Scheme, and increased energy capacity from prioritised Energy Zones in the Central West, South West, and New England regions of New South Wales.

3.1.2 Managing reactive power during maximum demand conditions

The closure of Liddell Power Station will reduce the amount of available reactive power in the New South Wales transmission network, requiring additional investment in reactive power infrastructure to maintain voltages above minimum secure operational levels. Failure to replace this reactive power capability would reduce interconnector transfer capability during peak demand periods – resulting in higher wholesale prices, and potentially necessitating load shedding to maintain a secure operating system.

The ISP Group 1 upgrade of the Queensland to New South Wales Interconnector is an important example of the integrated approach that includes additional reactive support at Armidale, Dumaresq, and Tamworth substations to meet this requirement.

Powerlink and TransGrid have recently commenced a RIT-T to explore options to deliver this ISP project[27].

3.1.3 Managing voltages during minimum demand conditions

The closure of Liddell Power Station will also make voltage control in northern New South Wales more challenging at times of minimum demand. The generation dispatch pattern in New South Wales at times of minimum demand following the closure of Liddell Power Station is projected to transition towards more non-synchronous plants spread out across the state. Whereas, the location and size of infrastructure providing the essential reactive support in the network has been designed around the existing generation fleet at its current locations and may no longer be adequate to control voltages.

The current projections suggest that these changes will result in higher voltages on the transmission network in northern New South Wales during minimum demand periods. This will require additional investment in

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[24] AEMO. *2018 ESOO*, available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/NEM-Electricity-Statement-of-Opportunities.

[25] See https://energy.nsw.gov.au/renewables/clean-energy-initiatives/emerging-energy-program.

[26] See https://energy.nsw.gov.au/renewables/emerging-energy/transmission-infrastructure-strategy.

[27] *Expanding NSW-QLD transmission transfer capacity, Project Specification Consultation Report*, available at https://www.powerlink.com.au/sites/default/files/2018-11/Project%20Specification%20Consultation%20Report%20-%20Expanding%20NSW%20Qld%20Transmission%20Transfer%20Capacity.pdf.

reactive power devices to maintain voltages below maximum safe operational levels during low demand periods. Failure to do so would risk damage to transmission and distribution infrastructure that could potentially create safety issues for consumers and risk damage to appliances.

Operation of the power system is becoming more difficult to manage due to increased variability of demand, for example as high levels of rooftop photovoltaics (PV) result in minimum demand periods in the middle of the day. Without prudent investment in reactive compensation, intervention – such as having to direct expensive fast start synchronous generation online to provide reactive support – will become a more frequent occurrence.

3.1.4 Managing system strength and minimum fault levels

A full discussion of system strength requirements across the NEM is in Section 3.2. In New South Wales, a minimum number of online synchronous machines is required to maintain minimum fault levels at the defined fault level nodes in the New South Wales network.

Following the closure of Liddell Power Station, and with a higher level of non-synchronous plant online, ISP studies project that the dispatch of synchronous plant in New South Wales could reduce to levels where these minimum fault levels might be reached.

AEMO will conduct further monitoring of actual minimum synchronous plant dispatch, and undertake detailed studies into projected minimum dispatch generation scenarios and minimum fault level requirements through 2019, to firm up projected requirements and options needed to manage the power system following the closure of Liddell Power Station.

3.2 System strength and inertia requirements

System strength is a measure of the ability of a power system to remain stable under normal conditions and to return to a steady state condition following a system disturbance. System strength is reduced when there is low synchronous generation in a region, and generally deteriorates further with high penetration of non-synchronous generation as the short circuit ratio[28] lessens.

Inertia is a system parameter of the interconnected power system that gives stability to power system frequency, especially following a contingency event that affects the supply-demand balance. Synchronous generation contributes to total inertia, while currently installed non-synchronous inverter-based generation generally does not. However, where suitably designed, non-synchronous generation technology can provide a FFR that can reduce the total inertia requirement.

3.2.1 Short-term projections

The 2018 ISP assessed whether system strength and inertia requirements would be met over the coming five-year period, and this NTNDP elaborates further on these requirements.

System strength

The 2018 System Strength Requirements and Fault Level Shortfalls report[29] uses the concept of three phase fault level to quantify regional system strength requirements. A minimum fault level requirement is needed for power system protection equipment to work, for voltages changes to be manageable, and for generation to operate. The minimum fault levels are specified at defined fault level nodes and are the responsibility of the regional TNSP to maintain – including during planned outages and under a range of dispatch patterns (that is, with the minimum synchronous generation dispatched in the region, and with any single outage).

[28] The short circuit ratio is the synchronous three phase fault level (in MVA) at the connection point divided by the rated output of the generating unit or generating system (expressed in MW or MVA) (as applicable).

[29] AEMO. *System Strength Requirements*, available at http://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/System_Strength_Requirements_Methodology_PUBLISHED.pdf.

Based on AEMO's system strength requirements and ISP projections:

- South Australia – the fault level shortfall declared in South Australia will remain until ElectraNet's system strength solution is delivered[30]. High-inertia synchronous condensers (e.g. synchronous condensers with flywheels) have been demonstrated to be the most efficient solution to meet this shortfall.
- Queensland and Tasmania – these regions are projected to meet their minimum regional fault level requirements during system normal over the coming five years.
- New South Wales – following the closure of Liddell Power Station in late 2022, the ISP projects that while the minimum regional fault level requirements continue to be met, the expected minimum number of synchronous units online could reach the minimum operating requirement. Further detailed studies into the projected minimum dispatch generation scenarios and minimum fault level requirements for New South Wales will be undertaken by AEMO through 2019, to firm up projected requirements and options needed to manage the power system following the closure of Liddell Power Station.
- Victoria – during system normal, the Victorian grid typically meets the minimum system strength requirements at the defined fault level nodes. ISP projections show that the expected minimum number of synchronous units online already reaches the minimum operating requirement[31]. AEMO is currently conducting detailed studies to review and refine the minimum requirement, and to consider how this requirement is impacted when 500 kV lines are switched out of service for voltage control purposes.

The minimum fault level requirements must also be maintained during planned outages. An outage might reduce fault levels in an area. There are some areas of the NEM where existing non-synchronous generation may need to be curtailed during planned outages, because the fault level of the area would be reduced to a point where the system would otherwise be insecure. For example, if left unmanaged, a credible contingency could lead to undamped oscillations causing widespread system interruptions. The only way to manage the risk during these planned outages is to curtail non-synchronous generation. Examples of such areas are shown in Figure 1, and include:

- South Australia.
- North Western and Western Victoria (between Ballarat, Horsham, Red Cliffs, Kerang and Bendigo).
- South Western New South Wales (between Broken Hill, Buronga and Darlington Point).
- Northern Queensland (north of Calvale).
- Tasmania.

System strength requirements for new generation connections

In June 2018, AEMO published the System Strength Impact Assessment Guidelines[32], which detail the system strength assessment methods to determine any adverse system strength impacts required for connection of new generation plant, and the potential need for mitigation such as tripping schemes or installation of synchronous condensers. Figure 1 shows network locations where AEMO considers that low system strength will likely affect generator connections[33].

While it is a TNSP responsibility to maintain minimum fault levels at the defined fault level nodes, it is the responsibility of the connecting party to ensure the stability of their plant at these minimum fault levels, and to mitigate any adverse system strength impacts.

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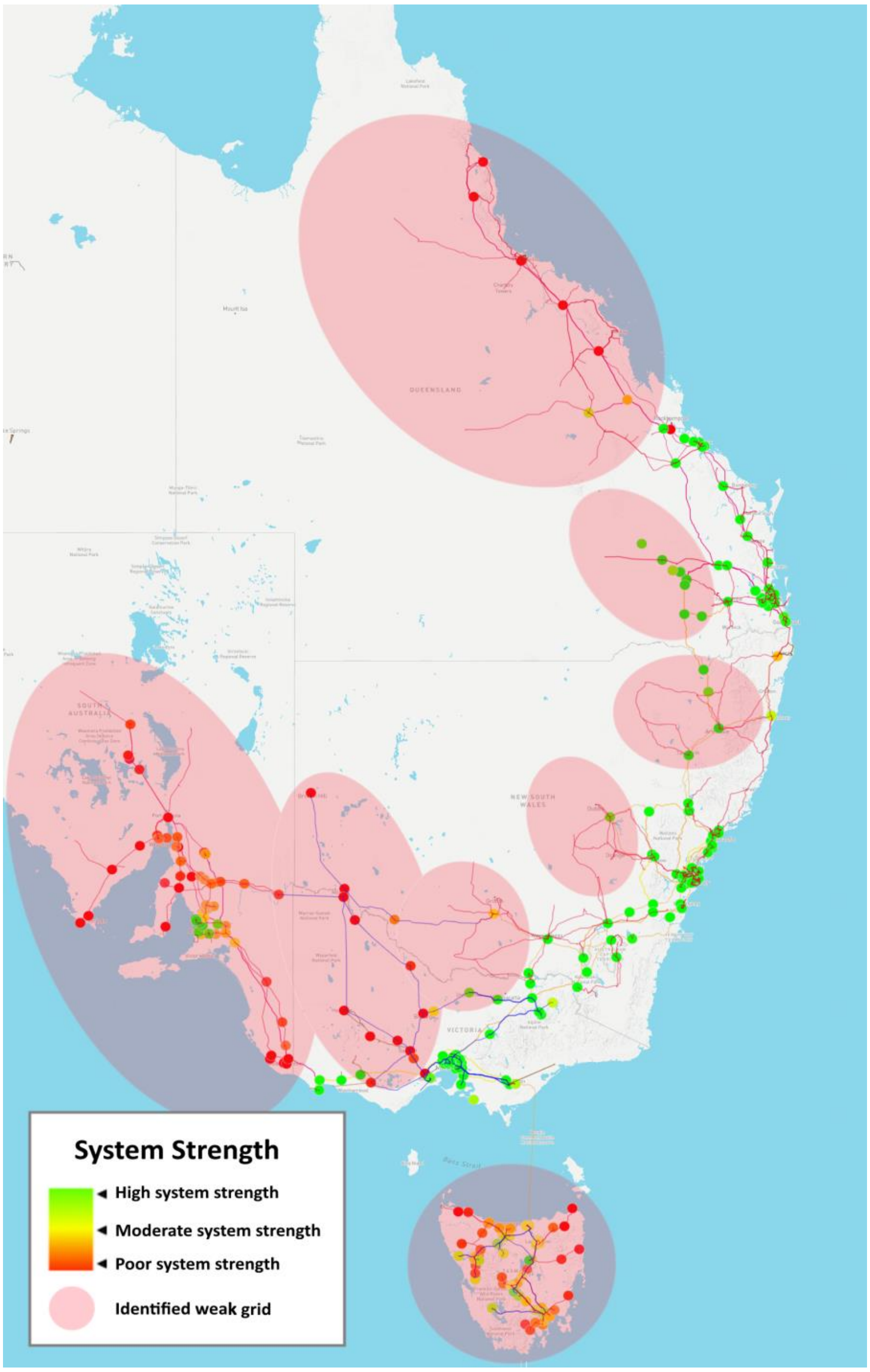
[30] ElectraNet. *Strengthening South Australia's Power System*, available at https://www.electranet.com.au/what-we-do/projects/power-system-strength/.

[31] Noting a direction of a synchronous unit to remain on due to unforeseen simultaneous outage of multiple units occurred on Saturday 17/11/2018.

[32] AEMO. *System Strength Impact Assessment Guidelines*, available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/System-Strength-Impact-Assessment-Guidelines.

[33] AEMO has assumed typical generation connection sizes, minimum fault level requirements, existing non-synchronous capacity, and known levels of connection interest.

Figure 1 Identified and emerging weak grid areas



Note that some areas with high system strength are flagged as emerging weak grid areas due to high levels of non-synchronous generator connection interest.

System strength remediation[34] is highly likely for non-synchronous generator connections in these weak-grid areas. The need for system strength remediation will increase as higher levels of non-synchronous plant continue to connect to the electrical network. System strength projections are available on AEMO's interactive map[35]. The ISP demonstrated that as non-synchronous generators continue to connect across the NEM, existing system strength will be depleted, and remediation measures will become unavoidable in many areas and a pre-requisite to further connection.

[34] System strength remediation options are outlined in the System Strength Impact Assessment Guidelines, available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/System-Security-Market-Frameworks-Review.

Even locations that were previously considered strong are starting to show reduced fault level headroom for new connections, due to the large number of recent and active generator connection proposals. This highlights that the availability of network locations with high system strength is quickly declining and will continue to do so without appropriate investment.

Proponents planning to connect new generation projects should consider the requirements of a full system strength impact assessment, the implications from this on future operations, and the potential impacts on their development timeframes and costs of any remediation requirements.

For situations where the fault level is reduced, for example during network outages, limitations on non-synchronous generation are anticipated to increase. Due to the large number of connection proposals in North Western and Western Victoria and South Western New South Wales, AEMO is currently progressing further detailed studies that will inform policies for connection and operation of clusters of generation in the region.

Inertia

AEMO's Inertia Requirements and Shortfalls report[36] defines the method used to assess the adequacy of minimum inertia in each inertia sub-network (currently defined by reference to region boundaries). The minimum inertia requirements are critical when separation is credible.[37]

Based on the minimum inertia requirements and ISP projections:

- New South Wales, Queensland and Tasmania are projected to meet their minimum inertia requirements.
- While Victoria is projected to, at times, have less inertia than the secure operating level, a shortfall has not been declared due to the low risk of islanding this NEM region.
- South Australia is projected to experience a minimum inertia shortfall (see Section 3.2.2).

Table 1 and Figure 2 show the detailed results of this assessment, comparing the actual and projected inertia with the secure operating level.

Table 1 Current and projected typical inertia, Neutral scenario

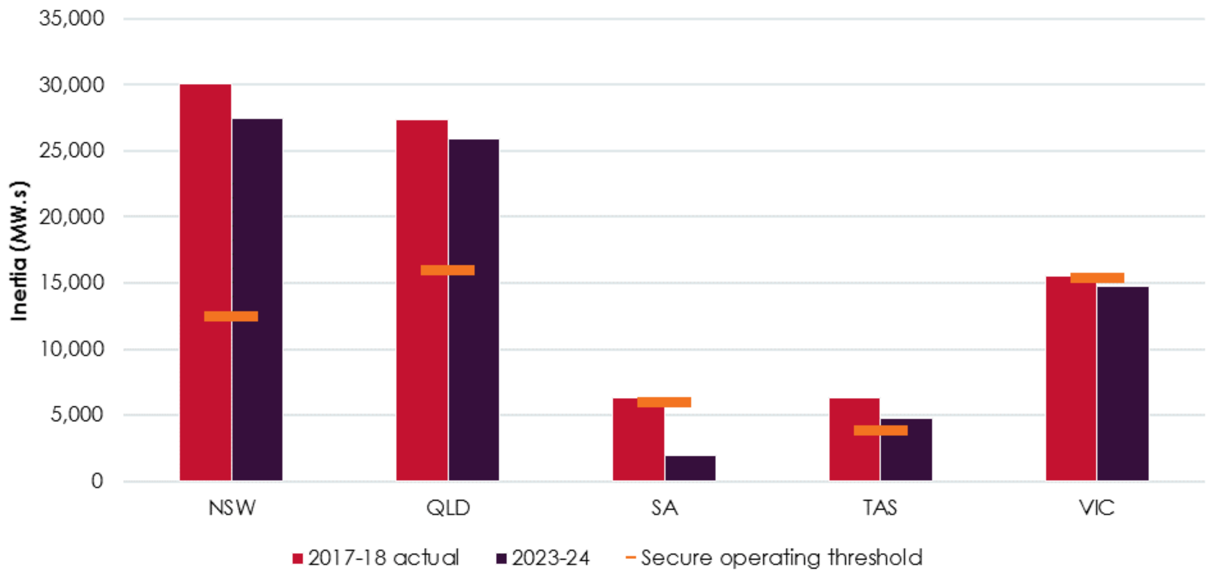
Region	Secure operating level of inertia (MWs)	Actual 2017-18 typical inertia (MWs)	Projected 2023-24 typical inertia (MWs)	Outcome
New South Wales	12,500	30,100	27,500	No shortfall
Queensland	16,000	27,400	25,900	No shortfall
South Australia	6,000	6,300	1,900 *	Shortfall (Refer to Section 3.2.2)
Victoria	15,400	15,500	14,700	No shortfall due to low risk of islanding
Tasmania	3,800	6,200	4,800 **	No shortfall

* South Australia projected inertia includes units being constrained on to meet minimum system strength requirements.
** Tasmania projected inertia does not include hydro units operating in synchronous condenser mode.

[36] AEMO. *Inertia Requirements*, available at http://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/Inertia_Requirements_Methodology_PUBLISHED.pdf.

[37] Inertia requirements are assessed against typical levels of inertia in each sub-network. The typical level of inertia is currently defined as the level of inertia provided at one standard deviation below the mean.

Figure 2 Actual and projected typical inertia, Neutral scenario



3.2.2 South Australia minimum inertia and fault level shortfalls

AEMO declared a system strength gap in the South Australian region in the 2016 NTNDP. Since that time, a regulatory framework for system strength has been implemented. Under transitional rules, ElectraNet elected to treat this gap as a "fault level shortfall" under the new framework. AEMO is now working with ElectraNet to fast-track the implementation of the synchronous condensers to rectify the shortfall[38].

To maintain power system security, AEMO currently directs synchronous generating units to remain online in South Australia to meet system strength requirements[39]. To avoid ongoing market intervention, and to provide benefits to consumers, high-inertia synchronous condensers (e.g. synchronous condensers with flywheels) are urgently required in South Australia.

Inertia shortfall declared in South Australia

A minimum level of inertia is essential for stable and secure power system operation. Like system strength, inertia is provided by operating synchronous machines online. Synchronous machines have an inherent inertial response to balance any instantaneous difference between the electrical demand and actual generation production by rapidly and automatically injecting energy. Without this dampening effect, uncontrolled high rates of change of frequency could occur, with the potential for cascade tripping of large amounts of load and generation from the transmission system. Through rapid control of active power, FFR devices such as batteries can also support this need and alleviate the total requirements for synchronous machine inertia.

The "secure operating level" of inertia in South Australia is 6,000 MWs.

The inertia requirements for South Australia are currently being met as an additional outcome of the AEMO direction of a minimum number of synchronous generating units online in South Australia to address the declared fault level shortfall. When the fault level shortfall in South Australia is addressed by ElectraNet installing synchronous condensers, unless otherwise incentivised in the market, AEMO expects that there will be times where there are no current synchronous generating units online.

[38] ElectraNet. *Power System Strength*, available at https://www.electranet.com.au/wp-content/uploads/2018/05/generation, as well as the 180515_ElectraNet_System-Strength_Fact-Sheet_WEB.pdf.

[39] AEMO. *South Australian System Strength Limit Advice*, available at http://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Congestion-Information/2018/Transfer-Limit-Advice---South-Australian-System-Strength.pdf.

As a result, AEMO is declaring an inertia shortfall in the South Australia region of 6,000 MWs in the next five years. AEMO recommends that ElectraNet procure inertia services to ensure that the secure operating level of 6,000 MWs is maintained for all operating dispatch patterns when South Australia is islanded. In doing so, AEMO recommends that:

- ElectraNet procure at least 4,400 MWs of inertia services through synchronous condensers or contracting with synchronous generation, coinciding with the time at which ElectraNet meets the declared fault level shortfall. In conjunction, ElectraNet should:
  - Ensure this 4,400 MWs of inertia can be online for periods when the South Australian region is at a credible risk of islanding[40].
  - Equip the synchronous condensers with flywheels as an efficient means of supplying both system strength requirements and providing additional inertia needed to maintain a secure operating state.
  - Consider contracting of non-synchronous generation and batteries that can provide FFR to provide additional inertia services up to the secure operating level.

3.3 Voltage control during low demand periods

AEMO has performed load flow analysis to determine if there would be any voltages outside their limits during the normal operation of the network, to determine if any NSCAS is required over the next five years.

The analysis focused on the following regions:

- South Australia and Victoria – the networks experience high voltages during periods of low synchronous generation and low operational demand. When all the usual methods of voltage control have been exhausted, AEMO has resorted to operational measures such as de-energising lines or directing synchronous generation to remain online.
- New South Wales – the control of high voltages is currently adequate, managed through switching reactive devices and constraint equations. The closure of Liddell Power Station in 2022 represents a major change to the New South Wales network, which could lead to higher voltages during minimum demand periods.

3.3.1 Voltage control in South Australia

The South Australian transmission network is projected to experience high voltages during minimum demand conditions. AEMO's assessment has not identified an NSCAS gap over the next five years, as high voltages can be managed using existing plant, planned synchronous condensers, and temporary operational measures (for example, de-energising the Magill – East Terrace 275 kV cable).

The system strength requirements, outlined in Section 3.2.1, dictate a minimum synchronous generation dispatch in South Australia. The reactive power capability that is provided by generation to support system strength needs, and the reactive power that will be delivered by ElectraNet's planned system strength solution, will support the increasing need for reactive power during low demand conditions.

Another mitigation option is to revise voltage set points on Static VAr Compensators (SVCs) in South Australia to ensure the SVCs are not saturated during light loading conditions. Also, the connection of new generation will provide additional reactive capability to the network, assisting with voltage control.

ElectraNet plans to install synchronous condensers and additional new reactors in the 275 kV network over the next five years, as outlined in their 2018 TAPR[41]. Locations, reactive capabilities, and expected completion dates of the synchronous condensers have not yet been finalised. When more details are known, AEMO will

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[40] This also includes coverage for any protected events, or times when non-credible contingencies are reclassified as credible, which could result in the South Australian region being islanded.

[41] ElectraNet. *2018 Transmission Annual Planning Report*, available at https://www.electranet.com.au/resources/2018-transmission-annual-planning-report/.

reassess NSCAS requirements for South Australia. AEMO recommends that voltage control under minimum demand should be a consideration, in addition to system strength and inertia, when determining the location and sizing of the synchronous condensers.

3.3.2 Voltage control in Victoria

Under minimum demand conditions, and without operator action, high voltages[42] can occur in Victoria following credible contingencies[43] and in some cases in under normal (pre-contingent) operation. Short-term operational measures, such as de-energising lines, have been applied during periods of minimum demand.

The frequency and extent of these operator actions has increased more rapidly than previously anticipated. In November 2018, AEMO was required to de-energise three 500 kV lines and issue directions to maintain Victorian voltages within operating limits in low demand periods due to multiple generating unit outages. As the frequency of these operator actions increases, there is an increasing risk that power system security and reliability will not be maintained within required standards. In response, AEMO has identified that an NSCAS gap for voltage control exists now in Victoria.

AEMO, in its Victorian planning role, is investigating the need for short-term measures through contractual arrangements and minor augmentation work as early as practicable. Accordingly, no NSCAS tender date is specified.

High voltages under minimum demand are likely to persist, requiring a longer-term solution. Recent government announcements have incentivised more DER[44], which could further reduce the minimum demand. AEMO has initiated a Victorian Reactive Power Support RIT-T to identify a preferred long-term option to manage voltages in Victoria. Further information can be found in the RIT-T Project Specification Consultation Report (PSCR)[45].

3.3.3 Voltage control in New South Wales

The closure of Liddell Power Station, together with increasing renewable generation, is likely to result in higher voltage across the New South Wales network during minimum demand periods (see Section 3.1.3).

This increased voltage across New South Wales during minimum demand is likely to bring the existing high voltage conditions in Southern New South Wales closer to its upper limit. AEMO currently utilises six reactors and a tripping scheme in this region to manage high voltage issues under system normal conditions. TransGrid and AEMO may need to explore other operational measures to control high voltage with higher penetration of committed renewable generation in New South Wales.

3.4 Credible contingencies affecting multiple generating units

New contingencies are emerging that disconnect or runback multiple generating units. This is occurring in areas where multiple generators are connected radially or are disconnected simultaneously due to special protection schemes in low system strength areas.

For example:

- In Victoria, a credible line contingency could result in the tripping of multiple wind farms and also impact the interconnector. During times of high wind generation, this could represent a significant loss of generation, and could become the largest single contingency in the Victorian system.
- In New South Wales, a credible line contingency can disconnect multiple solar farms.

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[42] Voltage in excess of equipment's technical limits, or the voltage defined in clause S5.1a.4 of the NER.

[43] A credible contingency event is defined in clause 4.2.3 (b) of the NER as a contingency event the occurrence of which AEMO considers to be reasonably possible in the surrounding circumstances, including the technical envelope.

[44] *Solar Victoria, Solar Homes Package*, available at https://www.solar.vic.gov.au/.

[45] AEMO. *Victorian reactive power support, RIT-T Project Specification Consultation Report*, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/Victorian_Transmission/2018/Victorian-reactive-power-support-RIT-T-PSCR.pdf.

These large single contingencies may require implementation of new operational constraints to manage system security in the area, including considerations such as voltage stability, transient stability, thermal limitations, or frequency control ancillary service (FCAS) availability.

A1. NSCAS assessment

A1.1 Types of NSCAS

NSCAS[46] are non-market ancillary services that may be procured by TNSPs (or by AEMO as a last resort) to maintain power system security and reliability, and to maintain or increase the power transfer capability of the transmission network.

There are currently three types of NSCAS:

1. Network Loading Ancillary Service (NLAS).
   - Maintains power flow in transmission lines within capacity ratings following a credible contingency event; and maintains or increases the power transfer capability of that transmission network, by allowing increased loading on transmission network components.
2. Voltage Control Ancillary Service (VCAS).
   - Maintains the transmission network within voltage stability limits, and
   - Maintains or increases the power transfer capability of that transmission network, by improving voltage control and voltage stability.
3. Transient and Oscillatory Stability Ancillary Service (TOSAS).
   - Controls power flow into or out of the transmission network, to maintain the transmission network within its transient or oscillatory stability limits, and
   - Maintains or increases the power transfer capability of that transmission network, by improving transient or oscillatory stability.

A1.2 Summary of NSCAS contracts

There were two NSCAS contracts active during 2018. Table 2 shows the costs for NSCAS services procured for the last five years.

Table 2 NSCAS services and costs from 2014 to 2018

Facility	NSCAS Service	MVAr	NSCAS Contract End Date	Annual Cost				
				2013-14	2014-15	2015-16	2016-17	2017-18
Combined Murray and Yass substations	VCAS	800	30 June 2019	$3,195,62	$9,896,698	$10,055,572	$10,159,498	$10,375,519
Combined Murray and Tumut power stations	VCAS	700	30 June 2018	$41,301,706	$134,494	$171,797	$147,088	$3,842,236

[46] NSCAS information, procedures, and guidelines are available at https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Ancillary-services/Network-support-and-control-ancillary-services-procedures-and-guidelines.

A1.2.1 Murray and Yass substations

AEMO has a contract for 800 megavolt amperes reactive (MVAr) absorbing VCAS with TransGrid, including reactors at Murray Switching Station and Yass Substation. The contract commenced from 31 March 2014.

When the contract expires on 30 June 2019, TransGrid is expected to include the relevant network assets in its regulated asset base. TransGrid will then continue to provide the required voltage absorbing capability as a prescribed transmission service.

A1.2.2 Murray and Tumut power stations

AEMO's contract with Snowy Hydro for VCAS expired on 30 June 2018 and was not renewed. In collaboration with TransGrid, AEMO has implemented operational solutions to mitigate the need for this service.

A1.3 NSCAS gaps for maintaining power system security

The following sections present the outcomes from the 2018 NSCAS assessments.

A1.3.1 New South Wales

Voltage management and reactive power control have been assessed with Liddell Power Station, which had announced to retire in 2022, and the updated New South Wales maximum and minimum demand forecast. AEMO's assessment has not identified an NSCAS gap in New South Wales over the next five years.

A1.3.2 Queensland

South East Queensland may experience transmission line overloads or high bus voltages during certain operating conditions. These issues can be managed by line switching. AEMO's assessment has not identified an NSCAS gap in Queensland over the next five years.

A1.3.3 South Australia

This system strength shortfall was identified as an NSCAS gap in the 2016 NTNDP. Since then, the rules have been updated and ElectraNet has elected to treat this gap as a "fault level shortfall". In addition to the system strength gap, the South Australian transmission network may experience high voltages during light load conditions. This can be managed within acceptable limits using line switching and planned synchronous condensers. AEMO's assessment has not identified an NSCAS gap in South Australia over the next five years.

A1.3.4 Tasmania

The Tasmanian network can experience low system inertia, and difficulty with voltage control around the George Town area. Currently, system inertia is maintained at secure levels using a constraint equation that manages the Tasmanian generation mix and Basslink transfer levels. Voltage control can be managed using control schemes, voluntary generator dispatch from Hydro Tasmania, or by constraining Basslink transfer levels. TasNetworks installed a 40 MVAr capacitor bank at George Town 110 kV in March 2018. TasNetworks has also proposed a +/-50 MVAr STATCOM in the Georgetown area. AEMO's assessment has not identified an NSCAS gap in Tasmania over the next five years.

A1.3.5 Victoria

Under minimum demand conditions, high voltages in Victoria are becoming increasingly difficult to manage. Refer to section 3.3.2 for more information.

A1.3.6 NSCAS gaps for maximising market benefits

Table 3 provides a list of historical binding constraints which had market impact in excess of $50,000 in 2017 as identified in the 2017 NEM constraint report summary[47]. AEMO reviewed these constraints, proposed actions by TNSPs to address these constraints, and suggested actions to increase net market benefits. Accordingly, AEMO has not identified any NSCAS gaps for maximising market benefits.

Table 3 Assessment of significant binding constraint equations

Region	Network limitation	Market impact (2017)	Proposed action
NSW	N>>N-NIL__3_OPENED Avoid overloading of Liddell – Muswellbrook 330 kV line on trip of Liddell – Tamworth 330 kV line	$801,598	This constraint has been identified as part of Queensland to New South Wales Interconnector (QNI) upgrade and TransGrid/Powerlink included in the QNI RIT-T.
NSW	N^^Q_NIL_Bx, N^Q_NIL_B N^Q_NIL_A Avoid voltage collapse for loss of the largest Queensland generator or loss of Liddell – Muswellbrook 330 kV line	$556,067 (loss of largest Queensland generator) $110,138 (loss of Liddell-Muswellbrook 330 kV line)	This constraint has been identified as part of QNI upgrade and TransGrid/Powerlink included in the QNI RIT-T.
NSW	N^^V_NIL_1 Avoid voltage collapse in Southern NSW for loss of the largest Victorian generating unit	$736,587	TransGrid proposed priority project to install a 330 kV 100 MVAr shunt capacitor bank at Wagga substation.
NSW	N>>N-NIL__B_15M Avoid overloading of Upper Tumut– Canberra 330 kV line on trip of Lower Tumut – Canberra 330 kV line	$237,706	This constraint has been identified as part of Victoria to New South Wales (VNI) upgrade and TransGrid/AEMO included in the VNI RIT-T.
QLD	Q>NIL_BI_FB Boyne Island feeder bushing limit on Calliope River to Boyne Island 132 kV lines.	$589,995	In 2016, Powerlink considered to address this congestion by replacing Boyne Island transformers feeder bushing under network capability incentive parameter action plan (NCIPAP) project. Project was found not to be economically feasible.
QLD	Q:N_NIL_AR_2L-G & Q::N_NIL_AR_2L-G QLD to NSW import limitation due to transient stability limit on QNI for a 2 phase to ground fault at Armidale.	$151,610	This constraint has been identified as part of QNI upgrade and TransGrid/Powerlink included in the QNI RIT-T.
SA	S>NIL_HUWT_STBG Avoid overloading the Snowtown to Bungama 132 kV line if an outage of the Hummocks to Waterloo 132 kV line was to occur	$1,227,468	ElectraNet improved the application of dynamic line ratings on the Snowtown to Bungama 132 kV line to reduce the impact of this constraint.
SA	S>NIL_WERB_WEWT Avoid O/L Waterloo East-Waterloo 132 kV line on trip of Waterloo East-Morgan Whyalla 4 - Robertstown 132 kV line	$398,842	This constraint needs to be investigated for possible application of dynamic rating and/or other options to reduce market impact.
SA	S>V_NIL_NIL_RBNW	$112,551	A committed NCIPAP project is in progress. Target completion in 2018.

[47] AEMO. NEM Constraint Report Summary Data 2017. http://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Congestion-Information/2017/NEM-Constraint-Report-2017-summary-data.xlsx. Viewed 1 November 2018.

Region	Network limitation	Market impact (2017)	Proposed action
	Avoid overloading the North West Bend to Robertstown 132 kV line on no line trips		
	S>NIL_NIL_NWMH2 Avoid overload of North West Bend-Monash #2 132 kV line on no line trips.	$81,847	A committed NCIPAP project is in progress. Target completion in 2018.
VIC	V^SML_NSWRB_2 NSW Murraylink runback scheme, avoid voltage collapse for trip of Darlington Point to Buronga (X5) 220 kV line	$441,280	Implementation of the NSW Murraylink runback scheme will improve this limit.
	V>>SML_NIL_8 Avoid overloading Ballarat to Bendigo 220 kV line for loss of Shepparton to Bendigo 220 kV line	$185,106	An overload control scheme (SOCS) is in place to avoid/minimise pre-contingency load reduction.
	V::N_NIL_V2 Avoid transient instability for fault and trip of a Hazelwood to South Morang 500 kV line	$181,973	This constraint has been identified as part of VNI upgrade and TransGrid/AEMO included in the VNI RIT-T.
	V>>V_NIL_2A_R & V>>V_NIL_2B_R & V>>V_NIL_2_P V>>V_NIL_2_TIE Avoid overloading the South Morang 500/330 kV (F2) transformer for no contingencies	$143,896	This constraint has been identified as part of VNI upgrade and TransGrid/AEMO included in the VNI RIT-T.
	V>>V_NIL_5 Avoid overloading either Mount Beauty to Dederang 220 kV line (flow to North) for trip of the other Mount Beauty to Dederang 220 kV line	$86,009	2018 Victorian Annual Planning Review (VAPR) identified as 'monitored limitation' of Dederang-Mount Beauty 220 kV line loading. Invites solution which might deliver net market benefits.

A2. Limitations relating to NEM interconnectors

Interconnector	Limitation	Proposed Augmentation in 2018 ISP
Queensland to New South Wales interconnector (QNI)	Export to Queensland from New South Wales is limited by voltage collapse for loss of the largest generating unit in Queensland	Two options provided for increasing transfer between Queensland and New South Wales. Both options increase export and import levels between these two regions. (1) QNI Option 3 in the ISP: • Install SVCs at Dumaresq and Tamworth substations • Install shunt capacitor banks at Tamworth, Armidale and Dumaresq substations (2) QNI Option 5 in the ISP: • Augment existing substations/switching stations at Armidale, Dumaresq and Bulli Creek • Install Armidale-Dumaresq and Dumaresq-Bulli Creek additional new 330 kV double circuit line
	Export to Queensland from New South Wales is limited by thermal capacity of Liddell-Muswellbrook-Tamworth and Liddell-Tamworth 330 kV lines.	QNI Option 3 and Option 5 in the ISP: • Uprating of Liddell-Muswellbrook, Muswellbrook-Tamworth and Liddell-Tamworth 330 kV lines
	Export to New South Wales from Queensland is limited by the transient stability limits for a fault on either a Bulli Creek-Dumaresq or Armidale-Dumaresq 330 kV circuit.	Two options provided for increasing transfer between Queensland and New South Wales. Both options increase export and import levels between these two regions. (1) QNI Option 3 in the ISP: • Install SVCs at Dumaresq and Tamworth substations • Install shunt capacitor banks at Tamworth, Armidale and Dumaresq substations (2) QNI Option 5 in the ISP: • Install Armidale-Dumaresq and Dumaresq-Bulli Creek additional new 330 kV double circuit line • Augment existing substations/switching stations at Armidale, Dumaresq and Bulli Creek
Victoria to New South Wales interconnector (VNI)	Export to New South Wales from Victoria is limited when there is increased generation in Southern New South Wales (for example high existing Snowy generation and high wind and PV generation in Canberra and Yass area)	Uprating of several 330 kV circuits within New South Wales has been identified to address these constraints. These include: • Uprate Yass-Marulan (Line 4 & 5), Bannaby-Gullen Range (Line 61), Kangaroo Valley-Dapto (Line 18), Dapto-Avon (Line 11), Marulan-Avon (Line 16) and Marulan-Dapto (Line 8) 330 kV lines
	Export to New South Wales from Victoria is limited by thermal capacity of the South Morang 500/330 kV transformer	VNI Option 1 in the 2018 ISP: • Install a new 500/300 kV transformer at South Morang
	Export to New South Wales from Victoria is limited by thermal capacity of Dederang-South Morang 330 kV circuits	VNI Option 1 in the 2018 ISP: • Uprate South Morang – Dederang 330 kV lines by conductor re-tensioning

Interconnector	Limitation	Proposed Augmentation in 2018 ISP
	Export to New South Wales from Victoria is limited by thermal capacity of Upper Tumut-Canberra 330 kV line	VNI Option 1 in the 2018 ISP: • Uprate the Upper Tumut-Canberra 330 kV line
	Export to New South Wales from Victoria is limited by transient stability limit for a two phase to ground fault on a South Morang-Hazelwood 500 kV line	VNI Option 1 in the 2018 ISP: • Installation of a braking resistor at Loy Yang or Hazelwood 500 kV or battery storage or Flexible AC transmission system (FACTS) device.
	Export to Victoria from New South Wales is limited by thermal capacity of the Murray-Dederang 330 kV line	Proposed solutions include: • Automatic load shedding control scheme to manage potential overload on the Murray-Dederang 330 kV lines, and; • Additional reactive power support in Southern New South Wales.
	Export to Victoria from New South Wales is limited by thermal capacity of the Eildon-Thomastown 220 kV line	Automatic load shedding control scheme to manage potential overload on the Eildon-Thomastown 220 kV line.
	Export and Import between New South Wales and Victoria is limited by thermal capacity of existing transmission lines and voltage transient stability limits	The 2018 ISP identified the following augmentation in Group 3, referred to as SnowyLink South: • Install double circuit 500 kV lines: Sydenham-Ballarat-Bendigo-Kerang-Darlington Point-Wagga. • Install single circuit 500 kV line: Wagga-Bannaby-Snowy 2.0-Wagga. • Establishment of 500 kV terminal stations with 500/220 kV transformers at Ballarat, Bendigo and Kerang. • Establishment of 500 kV substations with 500/330 kV transformers at Darlington Point, Wagga and Snowy 2.0. • Power flow controllers on Bannaby-Sydney West, Dederang-Murray, Dederang-Wodonga 330 kV lines.
South Australia to Victoria interconnector (existing Heywood and Murraylink) South Australia to New South Wales interconnector	Transfer is limited in both directions by the interconnectors	Proposed new South Australia to New South Wales interconnector includes: • New Robertstown-Buronga-Darlington Point 330 kV double circuit line. • An additional 330 kV single circuit from Darlington Point-Wagga. • Two 275/330 kV transformers at Robertstown. • Four 330 kV Phase Shift transformers at Buronga. • A new 330/220 kV transformer at Buronga. • Reactive compensation.
Victoria to Tasmania interconnector (existing Basslink and proposed MarinusLink)	Victoria to Tasmania transfer in both directions is limited by the existing Basslink	2018 ISP modelling includes: • A HVDC cable between Port Latta/Smithton (TAS) and East Geelong (VIC) • Two 220 kV circuits between Port Latta/Smithton and Sheffield As part of the Project Marinus* RIT-T, connection points in Tasmania and Victoria are being reviewed.

* TasNetworks. Project Marinus, available at https://www.tasnetworks.com.au/our-network/planning-and-development/project-marinus-second-interconnector-assessment/.

Glossary

This document uses many terms that have meanings defined in the National Electricity Rules (NER). The NER meanings are adopted unless otherwise specified.

Term	Definition
active power	Also known as electrical power. A measure of the instantaneous rate at which electrical energy is consumed, generated or transmitted. In large electric power systems, it is measured in megawatts (MW) or 1,000,000 watts.
annual planning report	An annual report providing forecasts of gas or electricity (or both) supply, capacity, and demand, and other planning information.
augmentation	The process of upgrading the capacity or service potential of a transmission (or a distribution) pipeline.
capacity limited	A generating unit whose power output is limited.
committed project	Committed transmission projects include new transmission developments below $5 million that are published in the TNSPs' Annual Planning Reports, or those over $5 million that have completed a Regulatory Investment Test. Committed generation projects include all new generation developments that meet all five criteria specified by AEMO for a committed project.
connection point (electricity)	The agreed point of supply established between network service provider(s) and another registered participant, non-registered customer or franchise customer.
constraint equation	The mathematical expression of a physical system limitation or requirement that must be considered by the central dispatch algorithm when determining the optimum economic dispatch outcome. See also network constraint equation.
contingency	An event affecting the power system that is likely to involve an electricity generating unit's or transmission element's failure or removal from service.
consumer	A person or organisation who engages in the activity of purchasing electricity supplied through a transmission or distribution system to a connection point.
credible contingency	Any outage that is reasonably likely to occur. Examples include the outage of a single electricity transmission line, transformer, generating unit, or reactive plant, through one or two phase faults.
curtailed	See capacity limited.
customer	See consumer.
demand	See electricity demand.
distribution network	A network which is not a transmission network.
electrical energy	Energy can be calculated as the average electrical power over a time period, multiplied by the length of the time period. Measured on a sent-out basis, it includes energy consumed by the consumer load, and distribution and transmission losses. In large electric power systems, electrical energy is measured in gigawatt hours (GWh) or 1,000 megawatt hours (MWh).

Term	Definition
electrical power	Electrical power is a measure of the instantaneous rate at which electrical energy is consumed, generated or transmitted. In large electric power systems, it is measured in megawatts (MW) or 1,000,000 watts. Also known as active power.
electricity demand	The electrical power requirement met by generating units. The NTNDP reports demand on a generator-terminal basis, which includes: • The electrical power consumed by the consumer load. • Distribution and transmission losses. • Power station transformer losses and auxiliary loads.
energy	See electrical energy.
generating system	A system comprising one or more generating units that includes auxiliary or reactive plant that is located on the generator's side of the connection point.
generating unit	The actual generator of electricity and all the related equipment essential to its functioning as a single entity.
generation	The production of electrical power by converting another form of energy in a generating unit.
generation capacity	The amount (in megawatts (MW)) of electricity that a generating unit can produce under nominated conditions. The capacity of a generating unit may vary due to a range of factors. For example, the capacity of many thermal generating units is higher in winter than in summer.
generation expansion plan	A plan developed using a special algorithm that models the extent of new entry generation development based on certain economic assumptions.
generator	A person who engages in the activity of owning, controlling or operating a generating system that is connected to, or who otherwise supplies electricity to, a transmission or distribution system and who is registered by AEMO as a generator under Chapter 2 (of the NER) and, for the purposes of Chapter 5 (of the NER), the term includes a person who is required to, or intends to register in that capacity.
inertia	Produced by synchronous machines, inertia dampens the impact of changes in power system frequency, resulting in a more stable system. Power systems with low inertia experience faster changes in system frequency following a disturbance, such as the trip of a generator.
installed capacity	Refers to generating capacity (in megawatts (MW)) in the following context: • A single generating unit. • A number of generating units of a particular type or in a particular area. • All of the generating units in a region.
interconnector	A transmission line or group of transmission lines that connects the transmission networks in adjacent regions.
interconnector flow	The quantity of electricity in MW being transmitted by an interconnector.
limitation (electricity)	Any limitation on the operation of the transmission system that will give rise to unserved energy (USE) or to generation re-dispatch costs.
load	A connection point or defined set of connection points at which electrical power is delivered to a person or to another network, or the amount of electrical power delivered at a defined instant at a connection pint, or aggregated over a defined set of connection points.
maximum demand	The highest amount of electrical power delivered, or forecast to be delivered, over a defined period (day, week, month, season, or year) either at a connection point, or simultaneously at a defined set of connection points.
National Electricity Law	The National Electricity Law (NEL) is a schedule to the National Electricity (South Australia) Act 1996, which is applied in other participating jurisdictions by application acts. The NEL sets out some of the key high-level elements of the electricity regulatory framework, such as the functions and powers of NEM institutions, including AEMO, the Australian Energy Market Commission (AEMC), and the AER.

Term	Definition
National Electricity Market (NEM)	The wholesale exchange of electricity operated by AEMO under the NER.
National Electricity Rules (NER)	The National Electricity Rules (NER) describes the day-to-day operations of the NEM and the framework for network regulations. See also National Electricity Law.
national transmission flow path	That portion of a transmission network or transmission networks used to transport significant amounts of electricity between generation centres and load centres. This generally refers to lines of nominal voltage of 220 kV and above.
national transmission grid	See national transmission flow path.
National Transmission Planner	AEMO acting in the performance of National Transmission Planner functions.
National Transmission Planner (NTP) functions	Functions described in section 49(2) of the National Electricity Law.
network	The apparatus, equipment, plant and buildings used to convey, and control the conveyance of, electricity to consumers (whether wholesale or retail) excluding any connection assets. In relation to a network service provider, a network owned, operated or controlled by that network service provider.
network capability	The capability of the network or part of the network to transfer electricity from one location to another.
network congestion	When a transmission network cannot accommodate the dispatch of the least-cost combination of available generation to meet demand.
network constraint equation	A constraint equation deriving from a network limit equation. Network constraint equations mathematically describe transmission network technical capabilities in a form suitable for consideration in the central dispatch process. See also 'constraint equation'.
network limit	Defines the power system's secure operating range. Network limits also take into account equipment/network element ratings.
network limitation	Network limitation describes network limits that cause frequently binding network constraint equations, and can represent major sources of network congestion. See also network congestion.
network service	Transmission service or distribution service associated with the conveyance, and controlling the conveyance, of electricity through the network.
network service provider (NSP)	A person who engages in the activity of owning, controlling or operating a transmission or distribution system and who is registered by AEMO as a network service provider under Chapter 2 (of the NER).
non-credible contingency	Any outage for which the probability of occurrence is considered very low. For example, the coincident outages of many transmission lines and transformers, for different reasons, in different parts of the electricity transmission network.
non-network option	An option intended to relieve a limitation without modifying or installing network elements. Typically, non-network options involved demand-side participation (including post contingent load relief) and new generation on the load side for the limitation.
power	See 'electrical power'.

Term	Definition
power station	In relation to a generator, a facility in which any of that generator's generating units are located.
power system	The National Electricity Market's (NEM) entire electricity infrastructure (including associated generation, transmission, and distribution networks) for the supply of electricity, operated as an integrated arrangement.
power system reliability	The ability of the power system to supply adequate power to satisfy customer demand, allowing for credible generation and transmission network contingencies.
power system security	The safe scheduling, operation, and control of the power system on a continuous basis in accordance with the principles set out in clause 4.2.6 (of the NER).
reactive power	The rate at which reactive energy is transferred. Reactive power, which is different to active power, is a necessary component of alternating current electricity. In large power systems it is measured in MVAr (1,000,000 volt-amperes reactive). It is predominantly consumed in the creation of magnetic fields in motors and transformers and produced by plant such as: • Alternating current generators. • Capacitors, including the capacitive effect of parallel transmission wires. • Synchronous condensers. Management of reactive power is necessary to ensure network voltage levels remains within required limits, which is in turn essential for maintaining power system security and reliability.
region	An area determined by the AEMC in accordance with Chapter 2A (of the NER), being an area served by a particular part of the transmission network containing one or more major load centres of generation centres or both.
Regulatory Investment Test for Transmission (RIT-T)	The test developed and published by the AER in accordance with clause 5.6.5B, including amendments. The test is to identify the most cost-effect option for supplying electricity to a particular part of the network. It may compare a range of alternative projects, including, but not limited to, new generation capacity, new or expanded interconnection capability, and transmission network augmentation within a region, or a combination of these.
reliability	The probability that plant, equipment, a system, or a device, will perform adequately for the period of time intended, under the operating conditions encountered. Also, the expression of a recognised degree of confidence in the certainty of an event or action occurring when expected.
rooftop photovoltaic (PV)	Includes both residential and commercial photovoltaic installations that are typically installed on consumers' rooftops.
scenario	A consistent set of assumptions used to develop forecasts of demand, transmission, and supply.
security	Security of supply is a measure of the power system's capacity to continue operating within defined technical limits even in the event of the disconnection of a major power system element such as an interconnector or large generator.
substation	A facility at which two or more lines are switched for operational purposes. May include one or more transformers so that some connected lines operate at different nominal voltages to others.
supply	The delivery of electricity.
transmission network	A network within any participating jurisdiction operating at nominal voltages of 220 kV and above plus: • Any part of a network operating at nominal voltages between 66 kV and 220 kV that operates in parallel to and provides support to the higher voltage transmission network. • Any part of a network operating at nominal voltages between 66 kV and 220 kV that is deemed by the Australian Energy Regulator (AER) to be part of the transmission network.