VICTORIAN ANNUAL PLANNING REPORT

ELECTRICITY TRANSMISSION NETWORK PLANNING FOR VICTORIA

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AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

IMPORTANT NOTICE

Purpose

The purpose of this publication is to provide information relating to electricity supply, demand, network capability and development for Victoria's electricity transmission declared shared network.

AEMO publishes the *Victorian Annual Planning Report* (VAPR) in accordance with clause 5.12 of the National Electricity Rules. This publication is based on information available to AEMO as at 31 March 2017, although AEMO has incorporated more recent information where practical.

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Version control

Version	Release date	Changes
1	15/6/2017	

EXECUTIVE SUMMARY

The Australian Energy Market Operator (AEMO) is responsible for planning and directing augmentation on the Victorian electricity transmission Declared Shared Network (DSN), and for publishing the *Victorian Annual Planning Report* (VAPR). The VAPR considers the adequacy of the DSN to meet future reliability and security needs efficiently over the next 10 years.

Key insights of the 2017 VAPR

Victoria's power system is undergoing unprecedented change, and it is critical that reliability of supply to consumers is maintained during this transition.

- **The power system is in transition.** Four trends being seen in Victoria can influence future power system resilience:
  - Aging transmission infrastructure.
  - Reducing minimum grid demand.
  - Withdrawal of coal-fired generation.
  - Reducing system strength.[1]

  AEMO has investigated the impact of these trends and defined strategies for maintaining resilience as the power system is modernised.
- **Some network augmentation is required.** The pathway to a low-carbon future requires some increases in network capacity, to enable the:
  - Transport of large quantities of renewable generation from wind and solar resource-rich areas to demand centres within Victoria.
  - Sharing of excess renewable generation between regions of the National Electricity Market (NEM), by improving interconnection between states.
- **Demand response and Distributed Energy Resources (DER) are key to a successful power system transition.** Demand response and DER[2] can play a key role in maintaining the supply demand balance, including locating storage and generation close to, or embedded within, demand centres.
- **The regulatory framework needs updating.** The existing National Electricity Rules (NER) do not address all future challenges for maintaining system security. The Australian Energy Market Commission (AEMC) is consulting on a number of rule changes and framework reviews which AEMO is supporting, such as the System Security Markets Frameworks Review.[3]

Performance in review

Over the past 12 months, the Victorian DSN has performed as designed under normal operating conditions. With all primary DSN infrastructure in service, no DSN lines were overloaded and no load shedding due to DSN limitations occurred.

There was one incident resulting in loss of customer load when primary DSN infrastructure was out of service, and five incidents where the system was insecure during outages, where a further contingency would have breached operational limits. AEMO's review of these incidents found the level of major

[1] System strength is an inherent characteristic of any power system – it is a measure of the resilience of a power system to withstand and recover from system disturbances under all reasonably possible operating conditions. For more information, see the fact sheet available at: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/AEMO-Fact-Sheet-System-Strength-Final-20.pdf

[2] Demand response means customers reducing or shifting their consumption in response to market price or network reliability signals. DER are small generation or load shifting systems located behind the meter, on customers' premises. They typically range from around 1 kilowatt (kW) to tens of megawatts (MW) but, when aggregated, have the potential to benefit the power system and consumers.

[3] AEMC. *System Security Markets Frameworks Review*. Available at: http://www.aemc.gov.au/Major-Pages/System-Security-Review.

network investment required to minimise the impact of these incidents would be unlikely to be economically justified, given their low probability of occurrence.

Maintaining power system resilience

AEMO has investigated the impacts of the following trends being observed in Victoria, and defined strategies for maintaining system resilience as the power system is modernised:

- **Aging transmission infrastructure.** The DSN is aging, with most transmission lines more than 40 years old, and the frequency of planned maintenance of transmission infrastructure is expected to increase. AEMO is working with key stakeholders and network asset owners to minimise the potential impact of planned outages of key network components on system security and customer reliability.
- **Minimum grid demand being projected to halve in Victoria over the next decade.** This reduction is forecast to be driven largely by increasing rooftop solar photovoltaic (PV) installation and improvements in energy efficiency. Low minimum demand can lead to high voltages due to lightly loaded transmission lines. These high voltages can, if in excess of operating limits, threaten the continued operation of the power system:
  - Temporary operational measures have successfully been applied during periods of minimum demand to maintain voltages within operating limits.
  - AEMO is assessing the benefits of additional reactive power support as a longer-term solution, and will pursue options for procurement as required.
  - AEMO recognises that some connection point minimum demands are reducing at a much faster rate than the regional total, and is examining the potential for localised issues in more detail.
- **Withdrawal of coal-fired generation.** The withdrawal of coal-fired power stations, and supply of energy from other sources in different locations, requires careful planning of the grid to manage power system reliability. AEMO has described the challenges in planning reports, specifically the 2016 *Electricity Statement of Opportunities* (ESOO)[4] and 2017 *Gas Statement of Opportunities* (GSOO).[5]

  AEMO has prepared readiness plans to address these challenges for summer 2017–18, under five key strategies:
  - Increasing electricity supply reserves and maximising electricity generation outputs.
  - Mitigating risks to the supply of fuel required to generate electricity.
  - Maximising electricity import and export capacity across borders.
  - Maximising transmission system resilience and recovery.
  - Maximising demand response arrangements and increased participation.
- **Reducing system strength.** Low system strength in north-western Victoria could potentially constrain generators using power electronic interface technology, such as wind and solar generators. If not constrained, low system strength could lead to unstable power system operation.

  The Western Victoria Renewable Integration Regulatory Investment Test for Transmission (RIT-T)[6] is investigating the requirements for prospective generation projects and will identify a preferred option for maintaining system strength above minimum levels.

4 AEMO. ESOO, November 2016. Available at: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/NEM-Electricity-Statement-of-Opportunities.
5 AEMO. GSOO, March 2017. Available at: https://www.aemo.com.au/Gas/National-planning-and-forecasting/Gas-Statement-of-Opportunities.
6 AEMO. *Western Victoria Renewable Integration RIT-T*. Available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Victorian-transmission-network-service-provider-role/Regulatory-investment-tests-for-transmission. The Project Specification Consultation report (PSCR) was published in April 2017 and the Project Assessment Draft report will be published in early 2018.

The regulatory framework needs updating, as the existing National Electricity Rules (NER) do not address all future challenges for maintaining system security. AEMO is collaborating with the AEMC in its System Security Market Frameworks Review, which is exploring approaches to address current and future challenges to maintaining system security. The review draws heavily on AEMO's Future Power System Security (FPSS) program[7], which is identifying the technical and operational requirements for maintaining power system security as the electricity landscape transforms.

- The AEMC review is canvassing information for three future rule changes relating to frequency control and system strength, with draft determinations due by end of June 2017 and rule changes potentially implemented by end of 2017.
- The outcomes of the AEMC review will clarify roles and obligations, particularly in relation to system strength. This will allow AEMO to apply the outcomes in its assessments in the next stage of the Western Victoria Renewable Integration RIT-T.

Pathway to a low-carbon future

The Victorian Renewable Energy Target (VRET[8]) is incentivising mass deployment of new large-scale renewable generation to meet the 40% renewables target by 2025. This represents the most rapid rate of new generation connection the Victorian power system has experienced to date, and a major relocation of energy production in the Victorian network (from Latrobe Valley to western Victoria).

The strategies AEMO is employing to manage this transition include:

- **Increasing network capacity to transport renewable generation from wind and solar resource-rich areas to demand centres within Victoria.**
  - There is currently a high level of generation connection interest in western Victoria due to its natural resources. The generation capacity being considered exceeds existing network capacity.
  - Increased capacity in the western Victorian transmission network will be required relieve network congestion and realise the potential of new generation.
  - AEMO has initiated the Western Victoria Renewable Integration RIT-T[9] noted above to identify a preferred option for increasing capacity in western Victoria. The RIT-T considers a range of scenarios to ensure optimal options are identified. Non-network solutions will form part of the preferred option, where these can be sourced efficiently.
- **Improving interconnection so excess renewable generation can be shared between states.**
  - AEMO's analysis shows that increasing the export capability of the existing Victoria – New South Wales transmission interconnection is likely to be economically justifiable under the market benefits test of the current regulatory framework.
  - AEMO will commence a pre-feasibility assessment within the next 12 months, once there is more certainty on the preferred options from the Western Victoria Renewable Integration RIT-T and South Australia Energy Transformation RIT-T.[10]
- **Maximising the benefits realisable from demand response and DER.**
  - Demand response and DER can play a key role in maintaining the supply demand balance for continued reliable supply of electricity to consumers as the power system is modernised.
    - The location of storage and generation close to, or embedded within, demand centres could improve the benefits realisable from these new supply sources.

7 AEMO. Future Power System Security Program. Available at: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/FPSSP-Reports-and-Analysis.
8 Victorian Government. Renewable Energy Targets, June 2016. Available at: http://www.vic.gov.au/news/renewable-energy-targets.html.
9 AEMO. *Western Victoria Renewable Integration RIT-T*. Available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Victorian-transmission-network-service-provider-role/Regulatory-investment-tests-for-transmission.
10 ElectraNet. *South Australian Energy Transformation RIT-T*. Available at: https://www.electranet.com.au/projects/south-australian-energy-transformation/. This RIT-T explores the feasibility of a new interconnector between South Australia and other NEM regions.

  - AEMO will investigate the potential for demand response to improve system reliability, with particular focus on the immediate benefits for the coming summers.
- AEMO is redeveloping its systems and processes to better integrate demand response and DER data. This will provide improved visibility of the drivers for changing consumer behaviour, allowing AEMO to better plan for future infrastructure needs.
  - AEMO is implementing changes which will allow demand response and DER aggregators to participate in ancillary service markets.[11] This is currently only open to participants registered to supply energy in the electricity markets.
  - AEMO is collaborating with overseas system operators, and will continue its strategic approach to demand response and DER under AEMO's FPSS programme and as part of its involvement with the GO15[12] initiative.
  - AEMO is also collaborating with the Energy Market Transformation Project Team, a working group of the Senior Committee of Officials of the Council of Australian Governments (COAG) Energy Council, to explore DER data collection mechanisms.

11 AEMO. *Amendment of the Market Ancillary Service Specification.* Available at: https://www.aemo.com.au/Stakeholder-Consultation/Consultations/Amendment-Of-The-Market-Ancillary-Service-Specification.

12 The GO15 initiative is a voluntary initiative of the world's 18 largest power grid operators, from six continents, which represent more than 70% of the world's electricity demand and provide electricity to 3.4 billion consumers. More information is available at: http://www.go15.org/.

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CHAPTER 1. INTRODUCTION

The Australian Energy Market Operator (AEMO) is responsible for planning and directing augmentation on the Victorian electricity transmission Declared Shared Network (DSN). The *Victorian Annual Planning Report* (VAPR) considers the adequacy of the DSN to meet future reliability and security needs over the next 10 years, and identifies development opportunities that may deliver net market benefits.

AEMO publishes the VAPR as part of its role as Victorian transmission planner under the National Electricity Law (NEL), in accordance with clause 5.12.1 of the National Electricity Rules (NER). This year's VAPR:

- Reviews the performance of the DSN throughout 2016–17, including performance at times of high network stress.
- Investigates the trends occurring in Victoria that can influence power system resilience, and defines strategies for maintaining resilience as the power system is modernised.
- Sets out the strategies AEMO is employing to manage the transition to a low-carbon future driven by the Victorian Renewable Energy Target (VRET), and investigates the technical challenges and uncertainties associated with the changing generation mix.
- Provides an update on network development opportunities identified in last year's VAPR, and presents new opportunities.

This report is supported by an online, user-friendly interactive map providing data and analysis for a range of National Electricity Market (NEM) topics including current and emerging development opportunities, transmission connection point forecasts, and national transmission plans.

1.1 Supporting material

A suite of resources has been published on the AEMO website to support the content in this report.

Table 1 2017 VAPR resources and links

Resource	Description and links
Interactive Map	Provides data and analysis for a range of NEM topics including emerging development opportunities, transmission connection point forecasts, short-circuit levels, and national transmission plans. http://www.aemo.com.au/electricity/planning/interactive-map
Historical DSN rating and loading workbook	Presents ratings and loadings for the 2016–17 maximum demand and high export periods presented in Chapter 2 and the interactive map. http://www.aemo.com.au/Electricity/Planning/Victorian-Annual-Planning-Report/VAPR-Supporting-Information
AusNet Services 2017 asset renewal plan	Outlines AusNet Services' transmission asset renewal process and provides a list of its planned asset renewal projects for the next 10-year period, including changes since last year and the various options considered. http://www.aemo.com.au/Electricity/Planning/Victorian-Annual-Planning-Report/VAPR-Supporting-Information
Constraint reports	AEMO uses constraint equations to operate the DSN securely within power system limitations. The constraint equations are implemented in the National Electricity Market Dispatch Engine (NEMDE), which dispatches generation to ensure operation within the bounds of power system limitations. AEMO's annual and monthly constraint reports detail the historical performance of these constraint equations. http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Congestion-information/Statistical-Reporting-Streams
Demand forecasts	AEMO's independent connection point forecasts for Victoria. http://www.aemo.com.au/Electricity/Planning/Forecasting/AEMO-Transmission-Connection-Point-Forecasting/Transmission-Connection-Point-Forecasting-Report-for-Victoria

CHAPTER 2. NETWORK PERFORMANCE

This chapter assesses the performance of the Victorian electricity transmission DSN over 2016–17.[13]

Key insights of this chapter

- The Victorian DSN performed as designed over the 2016–17 period under normal operating conditions. With all primary DSN infrastructure in service, no DSN lines were overloaded and no load was shed due to DSN limitations.
- There was one incident resulting in loss of customer load when primary DSN infrastructure was out of service, and five incidents where the system was insecure during outages, where a further contingency would have breached operational limits. AEMO's review of these incidents found the level of major network investment[14] required to minimise the impact of these incidents would be unlikely to be economically justified, given their low probability of occurrence.
- Increasing penetration of renewable generation within the distribution network has begun influencing Victorian network flows, resulting in more frequent reverse flows from the distribution to the transmission network.
- Despite not yet having any significant impact on historical DSN performance, the penetration of renewable generation is projected to increase due to the VRET. This may result in a more complex network to operate, requiring strong coordination between AEMO, Transmission Network Service Providers (TNSPs), and Distribution Network Service Providers (DNSPs).

The following sections summarise AEMO's analysis, and more detailed information is available on the AEMO Interactive Map.[15] Unless otherwise stated, generation is defined as all scheduled, semi-scheduled, and non-scheduled generation greater than 30 megawatts (MW), and does not include rooftop photovoltaic (PV).

2.1 How does AEMO assess network performance?

In evaluating the adequacy of the Victorian DSN over 2016–17, AEMO has regard to the following key network performance indicators:

- **Loading of transmission network elements at times of high network stress** – whether the transmission network had sufficient capacity to supply the load.
- **Reactive power adequacy at times of high network stress and low load periods** – the network's ability to maintain acceptable voltages throughout the network.
- **Notable power system incidents** – the frequency of incidents which resulted in system security violation or loss of customer load or generation.
- **Interconnector capability** – the extent to which the operational limits of interconnectors restricted the import or export of generation.
- **Impact of constraint equations** – how much impact the transmission network had on generation dispatch.
- **Impact of renewable generation on the network** – how changing behaviours in the network due to renewable generation are impacting its operation.

[13] "2016–17" in this chapter refers to the analysis period 1 April 2016 to 31 March 2017. Hazelwood Power Station closed on 29 March 2017 so its impact on network performance indicators assessed in this chapter is minimal. However, impacts of the closure are discussed in Section 2.6.2.
[14] Major investment includes high cost augmentation such as new transformers and lines.
[15] AEMO. Interactive Map. Available at: http://www.aemo.com.au/aemo/apps/visualisations/map.html.

2.2 Network performance at times of high network stress

AEMO reviewed the loading of network elements to examine how stressed the network was during 2016–17. The Victorian DSN has three distinctive drivers of network stress:

- Maximum demand conditions (which typically occur on hot summer days) stress the network, as power transfers may exceed ratings of network elements.
- Under minimum demand conditions, voltages may exceed allowable operating limits.
- High network stress can also occur at times where high levels of Victorian generation are being exported to other regions, typically New South Wales.[16]

To understand how the network is performing at these times of high stress, AEMO used three 'snapshots'[17] to capture network conditions[18] during particular maximum demand, minimum demand, and high export[19] periods.[20]

Table 2 Summary of operational conditions

	Maximum demand snapshot	Minimum demand snapshot	High export from Victoria snapshot
Date and time*	9 February 2017 13:30:47	2 January 2017 04:00:47	23 May 2016 00:00:47
Victorian operational demand at time of snapshot**	8,404 MW	3,218 MW	4,455 MW
Sum of Victorian loads at time of snapshot	8,188 MW	3,038 MW	4,226 MW
Sum of Victorian generation at time of snapshot	9,221 MW	5,144 MW	5,623 MW
Sum of total Victorian available generation capacity at time of snapshot***	10,229 MW	7,212 MW	7,391 MW
Temperature in Melbourne	34.9 °C	13.1 °C	17.9 °C
Power flow from Victoria to South Australia (Heywood Interconnector)	565 MW	318 MW	30 MW
Power flow from Victoria to South Australia (Murraylink)	10 MW	14 MW	-157 MW
Power flow from Tasmania to Victoria	475 MW	-450 MW	0 MW
Power flow from Victoria to New South Wales	747 MW	1,115 MW	1,303 MW
Murray generation	1,272 MW	0 MW	0 MW
Renewable generation in Victoria Wind Hydro Rooftop PV	 561 MW 1,837 MW 604 MW	 371 MW 13 MW 0 MW	 722 MW 0 MW 0 MW
System security (N-1)	No system normal or contingency overloads	No system normal or contingency overloads	No system normal or contingency overloads

* All values listed, excluding temperature, are the values measured at the exact time of each snapshot for the region of Victoria.
** Operational demand is the sum of all Victorian loads and network losses.
*** Available generation capacity is the maximum capacity (MW output) at the time of the given snapshot. It reflects the maximum target a generator can be requested to reach within a given dispatch interval, and is equal to generation for all semi-scheduled and non-scheduled generators.

[16] The New South Wales interconnector has a higher transfer capacity than the Heywood or Basslink interconnectors.
[17] All DSN outages are maintained as at the time of the snapshot when assessing network adequacy.
[18] These snapshots do not necessarily represent the maximum load experienced by every DSN asset, as this depends on prevailing system conditions such as generation patterns, interconnector flows, and time of localised peak demand, as well as factors that influence dynamic ratings such as local temperature and wind speed.
[19] A high export period is classified as the snapshot with the highest flow through the South Morang F2 500/330 kilovolt (kV) transformer.
[20] The data is obtained from the state estimator, which estimates the states (such as power, voltages, and angles) of the power system based on certain measurements in AEMO's Energy Management System (EMS).

2.2.1 Maximum demand snapshot

The maximum demand snapshot captures the conditions when many network elements are under their maximum loading for the year. This section is complemented by additional detail in the historical DSN rating and loading workbook (see Section 1.1).

Figure 1 Maximum demand snapshot: generation, load, and interconnector flow

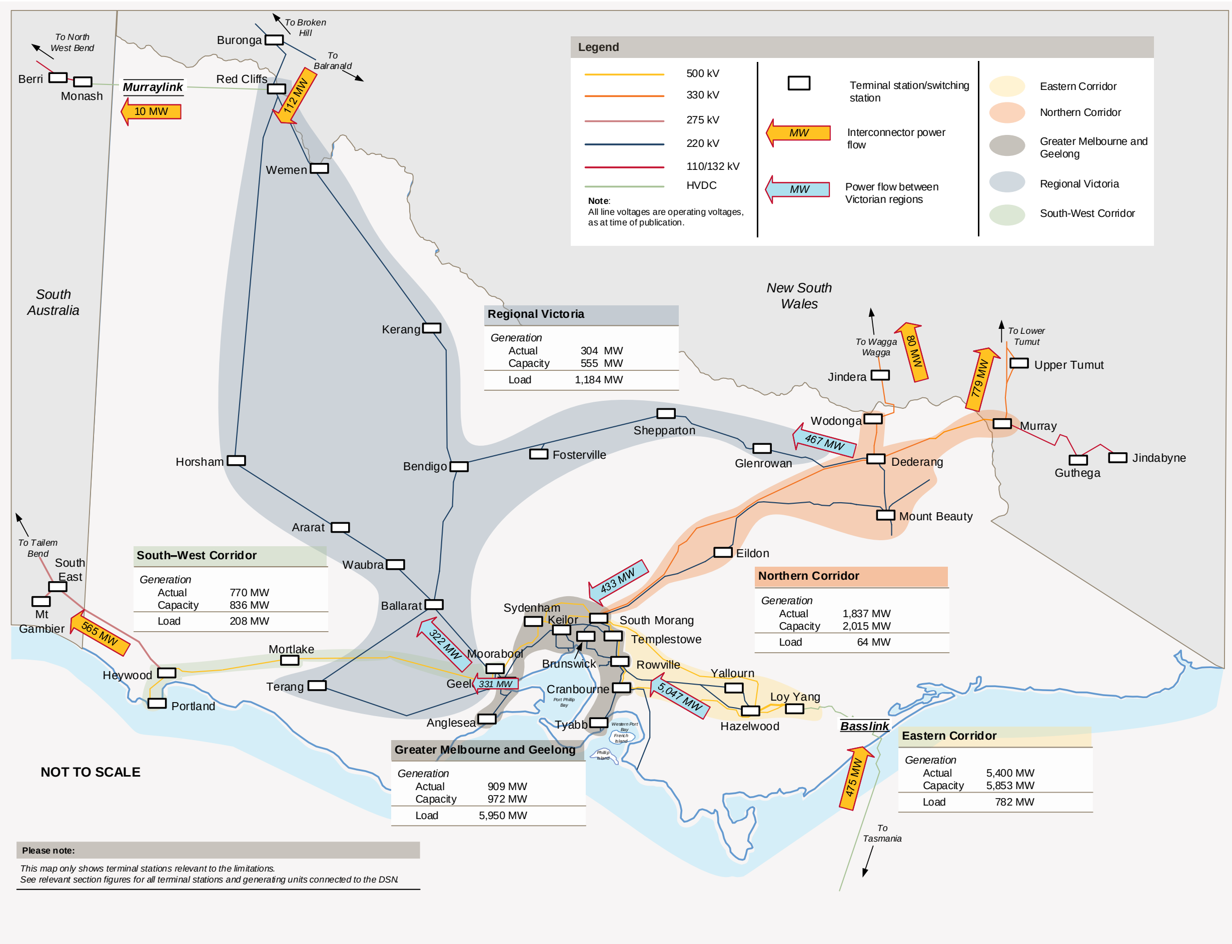


Figure 1 reflects the prevailing conditions at the time of Victorian maximum demand (13:30:47 on 9 February 2017). It shows the electrical regions and their interconnectors, and the transmission lines and their voltages. The arrows indicate power flow from one Victorian electricity region to another, and the lines represent single or multiple transmission lines.

The figure shows that at the time of the maximum demand snapshot:

- 73% (5,950 MW) of the total Victorian load (8,188 MW) was concentrated in Greater Melbourne and Geelong.
- The majority of Victorian generation originated from the Eastern (59%) and Northern Corridors (20%), with power flowing from these regions to Greater Melbourne, Geelong, and Regional Victoria.
- Net power flow from Victoria to New South Wales was 747 MW. This comprised an export of 859 MW from Murray and Wodonga, and an import of 122 MW from Buronga on the New South

Wales – Victoria interconnector. Net power flow from Victoria to South Australia comprised 565 MW via the Heywood Interconnector and 10 MW via the Murraylink Interconnector.[21]
- Power flow from Tasmania to Victoria comprised 475 MW via the Basslink interconnector.

All Victorian interconnector flows were well below their thermal limits.

In addition to Figure 1, at the time of the maximum demand snapshot, 91.4% of Victorian generation was available for dispatch, impacted by:

- 604 MW of rooftop PV generation, serving 6.9% of end user demand.[22]
- 2,398 MW of renewable generation (26.0% of total Victorian generation), comprised of non-scheduled wind (259 MW), dispatched wind (302 MW), and hydroelectric generation (1,837 MW).

A review of asset loading, including potential loading for a credible contingency, at the time of the maximum demand snapshot showed that the Victorian DSN performed adequately within technical network limits for secure operation.

2.2.2 Minimum demand snapshot

The minimum demand snapshot captures the conditions when voltages may exceed operating limits. This section is complemented by additional detail in the historical DSN rating and loading workbook (see Section 1.1).

[21] Active binding constraint equation was V>SML_NSWRB_10 – Avoid overload of Kerang to Wemen 220 kV line section for loss of Balranald to Darlington Point (X5/1) 220 kV line, when the Murraylink NSW runback scheme is out of service.

[22] Rooftop PV is not included in any generation or capacity values, but is included as a reduction in the recorded operational demand.

Figure 2 Minimum demand snapshot: generation, load, and interconnector flow

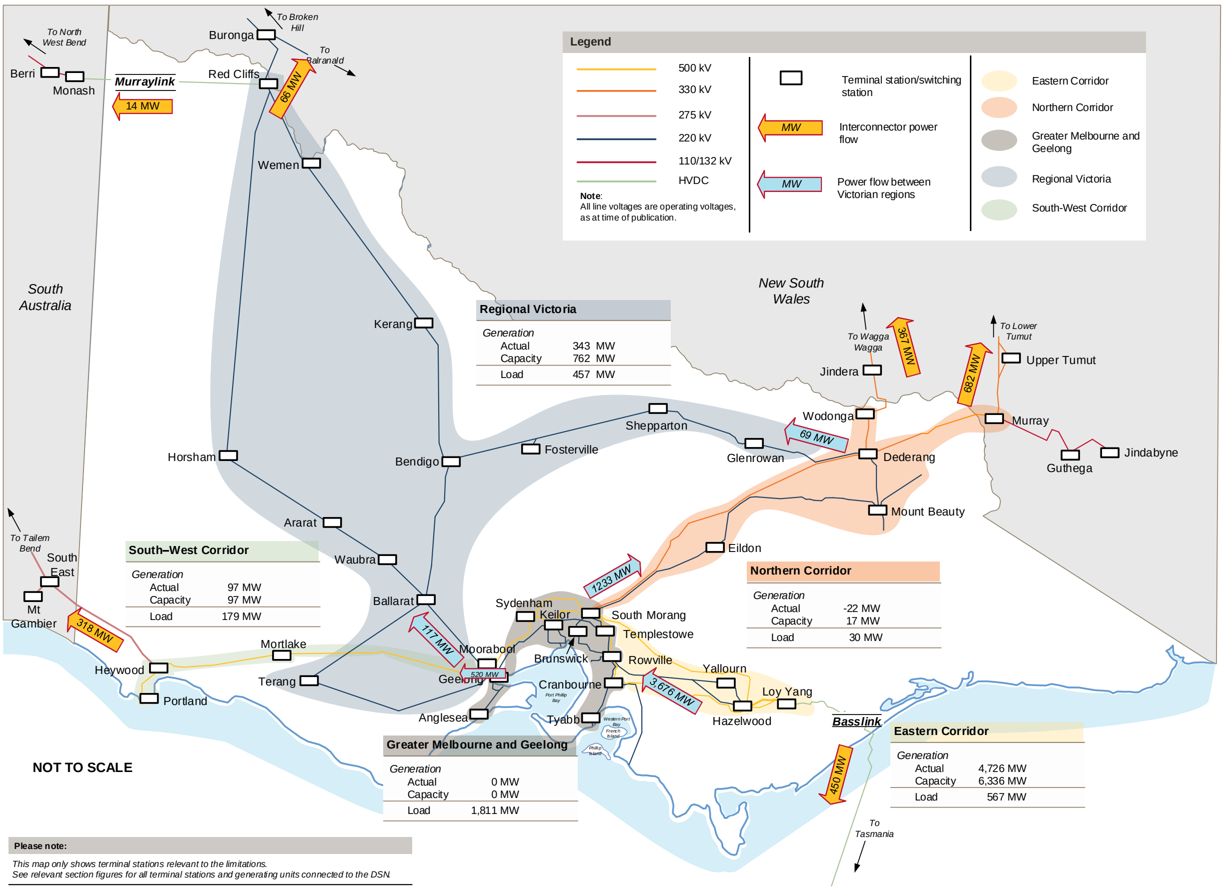


Figure 2 represents the prevailing conditions at the time of minimum demand in Victoria (04:00:47 on 2 January 2017). It shows:

- 59% (1,811 MW) of the total Victorian load (3,038 MW) was concentrated in Greater Melbourne and Geelong.
- The majority of Victorian generation (91.9%) originated from the Eastern Corridor.
- Net power flow from Victoria to New South Wales was 1,115 MW. This comprised an export of 1,049 MW from Murray and Wodonga, and 66 MW to Buronga on the New South Wales – Victoria interconnector.
- Net power flow from Victoria to South Australia was 332 MW, comprised of 318 MW on the Heywood Interconnector and 14 MW on the Murraylink interconnector.
- Power flow from Victoria to Tasmania was 450 MW via the Basslink interconnector.
- All interconnector flows were restricted by a constraint to manage pre-contingent overload of the South Morang F2 500/330 kV transformer.[23] This is explored further in Section 2.5.
- The Northern Corridor actual generation is negative (-22 MW), reflecting supply to local load at Jindabyne pump.[24]

In addition to Figure 2, at the time of the minimum demand snapshot:

[23] Constraint equation V>>V_NIL_2A_R.
[24] The Jindabyne Pump at Guthega (SNWYGJP2) moves water from Lake Jindabyne through the Jindabyne – Island Bend Tunnel to the Snowy –Geehi Tunnel at Island Bend. Refer to Snowy Hydro page for more information http://www.snowyhydro.com.au/our-energy/hydro/the-assets/power-stations/.

- There was no rooftop PV generation, because it was early in the morning before sunrise.
- There was 384 MW of renewable generation (7.5% of total Victorian generation), the majority of which was semi-scheduled and non-scheduled[25] wind generation.
- Over-voltage risk was successfully managed by existing reactive power plant and temporary operational measures.

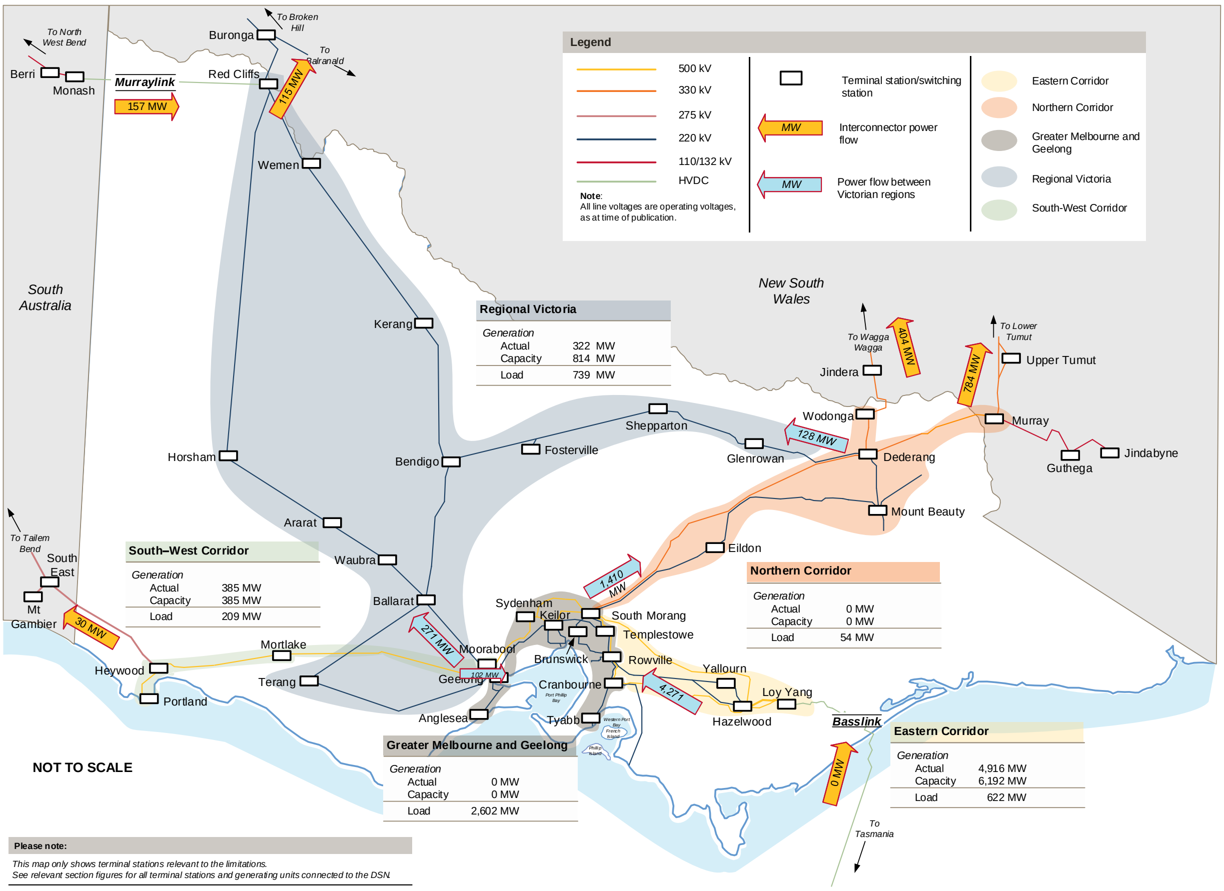
A review of asset loading at the time of minimum operational demand showed that the DSN performed within technical limits, with temporary operational measures successfully applied to maintain voltages within operating limits.

AEMO is forecasting a rapid reduction of Victorian minimum demand and, as a result, voltage management is expected to become more challenging in Victoria in the future. This is explored further in Section 3.5.

2.2.3 High Victorian export snapshot

The high Victorian export snapshot demonstrates network conditions during times of high export from Victoria to New South Wales, specifically through the South Morang F2 500/330 kilovolt (kV) transformer. This section is complemented by additional detail in the historical DSN rating and loading workbook (see Section 1.1).

Figure 3 High export snapshot: generation, load, and interconnector flow



[25] This resulted in a lower than average percentage of dispatchable generation. For the full spread of dispatchable generation throughout 2016–17, refer to the dispatchable generation duration curves found on the AEMO Interactive Map. Available at: http://www.aemo.com.au/aemo/apps/visualisations/map.html.

Figure 3 represents the prevailing conditions at the time of high export in Victoria (00:00:47 on 23 May 2016). It shows:

- 62% (2,602 MW) of total Victorian load (4,226 MW) was concentrated in Greater Melbourne and Geelong.
- The majority of Victorian generation (87%) originated from the Eastern Corridor.
- Net power flow from Victoria to New South Wales was 1,303 MW. This comprised an export of 1,188 MW from Murray and Wodonga, and 115 MW to Buronga on the New South Wales – Victoria interconnector.
- Export from Victoria to New South Wales was limited by the rating of the 500/330 kV South Morang F2 transformer. See Section 2.5 for more information about this constraint equation.
- There was no power transfer between Victoria and Tasmania, as the Basslink interconnector was out of service between 20 December 2015 and 13 June 2016 due to an unplanned outage.[26]
- Victoria was importing from South Australia. Net power flow from South Australia to Victoria was 127 MW, comprised of 157 MW import on the Murraylink interconnector and 30 MW export on the Heywood Interconnector.
- Interconnectors to South Australia (Heywood and Murraylink) were transferring at low levels into Victoria, less than a quarter of full capability. This was due to dispatch conditions rather than any network constraints.

In addition to Figure 3, at the time of the high export snapshot:

- No rooftop PV was generating, because the snapshot was at night.
- There was 722 MW of renewable generation, comprising 12.8% of total Victorian generation, with all renewable generation produced by wind.

A review of asset loading at the time of high Victorian export to New South Wales showed that the Victorian DSN performed within technical network limits for secure operation.

Improvement of the Victoria to New South Wales export capability to facilitate a changing generation mix is identified as an emerging development opportunity, and is explored further in Section 3.5.

[26] Basslink. Basslink Interconnector update, 13 June 2016. Available at: http://www.basslink.com.au/wp-content/uploads/2016/06/Media-statement-13-June-final1.pdf.

2.3 Victorian power system reviewable operating incidents

There were six notable incidents in the DSN in 2016–17, up from two in 2015–16:

- One incident resulted in loss of all load at Alcoa Portland Aluminium Smelter (APD).
- There were five incidents where the system was in an insecure state.[27]

The incident resulting in loss of all APD load (437 MW total) also resulted in loss of generation in Victoria, specifically at the Macarthur and Portland wind farms (9 MW total).

All six notable incidents occurred during outages.

At present, major investment[28] to minimise the impact of these incidents would be unlikely to be economically justified, due to their low probability of occurrence.

However, it is worth noting that the DSN is aging**,** with most transmission lines now more than 40 years old, and the frequency of planned maintenance of transmission infrastructure is expected to increase. Minor investment may be justified and AEMO is working with key stakeholders and network asset owners, on a case by case basis, to minimise the potential impact of planned outages of key network components on system security and customer reliability.

The six notable incidents are presented in Table 3.

Table 3 Significant reviewable power system incidents during 2016–17 (Summary)

Date	Incident	Consequence
01/12/2016	Power system insecure in Vic and SA	No loss of customer load
01/12/2016	South Australia Separation Event	Loss of customer load
30/11/2016	Power system insecure in Vic and SA	No loss of customer load
29/11/2016	Power system insecure in Vic	No loss of customer load
15/06/2016	Power system insecure in Vic	No loss of customer load
23/05/2016	Power system insecure in Vic	No loss of customer load

Detail on the above incidents, as well as a comprehensive list of power system operating incidents, is on AEMO's website.[29]

Because AEMO is responsible for operating the transmission network, this section does not consider distribution network events that may have resulted in loss of supply.

2.4 Interconnector capability over 2016–17

An interconnector's capability depends on the performance of the network, which varies throughout the year. A detailed summary of the capability and the limits of each interconnector in the NEM is provided in AEMO's Monthly and Annual NEM Constraint Reports.[30]

Updates on the status of the Basslink and Heywood interconnectors are as follows:

- The Basslink Interconnector was returned to service on 13 June 2016, transmitting power at full capability, after suffering a fault in late 2015.[31]

[27] An insecure state is a network condition in which a further contingency would have breached operational limits.
[28] Major investment includes high cost augmentation such as new transformers and lines.
[29] AEMO. Power System Operating Incident Reports. Available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Market-notices-and-events/Power-System-Operating-Incident-Reports.
[30] Monthly and Annual NEM Constraint reports are available through the Statistical Reporting Streams page at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Congestion-information/Statistical-Reporting-Streams.
[31] Basslink interconnector was taken offline for approximately five days from 8 March to 12 March 2017 to allow AGL to move its overburden stacker. This outage was planned and had no significant impact on the network.

- The Heywood Interconnector is being operated below its maximum design limit of 650 MW in both directions:
  - On 28 September 2016, when the South Australia Black System[32] occurred, the maximum transfer allowed on the interconnector was 600 MW (Victoria to South Australia) and 500 MW (South Australia to Victoria).
  - AEMO's analysis of the South Australia Black System event has identified a potential transient stability issue at high Victoria to South Australia transfer and high levels of wind generation in South Australia. AEMO will work with ElectraNet to review the transfer limits applied to the Heywood Interconnector to allow for the highest utilisation.
  - While the transient stability limit is being reviewed, the current limits of 600 MW (Victoria to South Australia) and 500 MW (South Australia to Victoria) will remain in place.[33]

2.5 Impact of Victorian transmission constraints

Table 4 summarises binding constraints on the Victorian transmission system that resulted in the highest market impact in 2016, with 2015 values shown for comparison. This is a subset of detailed constraint equation information in AEMO's Annual NEM Constraint Reports for 2015 and 2016.[34]

Table 4 Equations with persistent market impacts in both 2015 and 2016

ID	Equation ID	Binding hours		Market impact		Description
		2015	2016	2015	2016	
1	V^SML_NSWRB_2	73	154	$207,805	$518,333	To avoid voltage collapse for loss of Darlington Pt to Buronga (X5) 220 kV line when the NSW Murraylink runback scheme is not available.
2	V::N_NIL_xxx	1,091	1,054	$117,936	$238,531	To prevent transient instability for a trip of a HWTS-SMTS 500 kV line.
3	V>>SML_NIL_7B	35	33	$129,791	$123,287	To avoid overloading the Buangor to Ararat 66kV line for loss of the Ballarat to Waubra to Horsham 220 kV line.
4	V>>V_NIL_2A_R & V>>V_NIL_2B_R & V>>V_NIL_2_P	951	1,015	$97,980	$144,342	To avoid overloading the South Morang F2 transformer when Yallourn Unit 1 is in 220 kV mode and Hazelwood is operating in radial mode.
5	V>>SML_NIL_CONT_7B	20	101	$31,699	$146,166	To avoid overloading the Buangor to Ararat 66 kV line for a loss of the Ararat to Horsham 220 kV line.
6	V>>N-NIL_HA	36	368	$27,769	$97,517	To avoid Murray to Upper Tumut (65) overloading on Murray to Lower Tumut (66) trip.
7	V>SMLBAHO4	77	31	$34,142	$58,218	Bendigo to Kerang line out of service, avoid overloading the Buronga to Red Cliffs line for trip of either Ararat to Horsham or Ballarat to Ararat line.
Total		2,283	2,756	$647,122	$1,326,394	N/A

In 2016, the constraint equation with the largest market impact (constraint equation 1 in Table 4) restricted export to South Australia on the Murraylink interconnector, when the New South Wales

[32] AEMO. *Black System South Australia, 28 September 2016*, March 2017. Available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Market-notices-and-events/Power-System-Operating-Incident-Reports.

[33] AEMO. Update inter-network testing and transfer limit – Heywood interconnector. Available at: http://www.aemo.com.au/Market-Notices?currentFilter=&sortOrder=&searchString=56893.

[34] Monthly and Annual NEM Constraint reports, for the calendar year, are available through the Statistical Reporting Streams page on the AEMO website: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Congestion-information/Statistical-Reporting-Streams.

Murraylink interconnector runback scheme is out of service, to avoid voltage collapse for loss of Darlington Point to Buronga (X5) 220 kV line. This market impact has increased since 2015, and was driven by:

- Increased Murraylink flows, due to the improved thermal capacity between Robertstown and North West Bend in South Australia.
- Price volatility in South Australia, resulting from high wind generation variability.[35]

Potential measures to alleviate this constraint include:

- Dynamic reactive support – either a static VAR compensator (SVC) or a synchronous condenser (SC).
- Implementation of the New South Wales runback scheme, which will require reassessment and updating the current state of the scheme.

AEMO will engage with other TNSPs and the APA group (the owner and operator of the Murraylink interconnector) to determine the best course of action to reduce the binding hours of this constraint equation.

Two constraint equations, 3 and 5 in Table 4, are now obsolete and not expected to bind in the future. Constraint equation 5 was superseded by constraint equation 3 in June 2016, due to unavailable limited cyclic ratings, while constraint equation 3 was rendered obsolete by a new control scheme introduced in December 2016.

Improvements in constraint equations 2 and 4 may be addressed by pre-feasibility studies which AEMO will be commencing in the next 12 months to determine whether Victoria – New South Wales interconnector improvements are economically justified. These proposed improvements are discussed in more detail in Section 3.5.

Further Victoria – New South Wales interconnector limits are resulting from constraint equation 6, which is preventing higher export flows due to thermal limits on the Murray – Upper Tumut and Murray – Lower Tumut lines. This constraint equation is expected to bind less in the short term, due to lower export flows from Victoria resulting from the March 2017 retirement of the Hazelwood Power Station, but more frequently after additional renewable generation is connected as a result of VRET. AEMO will continue to monitor this constraint equation and may carry out joint planning with TransGrid if required to determine if an upgrade to these interconnector lines is economically justified.

2.6 Impact of changing generation mix

2.6.1 Renewable generation uptake

The level of renewable generation penetration in Victoria has increased over recent years, and is influencing Victorian network flows. The impact on network flows is expected to become more apparent as more renewable generation connects to the network due to the VRET.

This section reviews network performance under high renewable generation output, investigating effects on demand and network operation. It includes:

- A high wind ‘snapshot’ to assess network performance under high wind generation output.
- Frequency of reverse flow (from the distribution network into the DSN) occurrences as a result of renewable generation directly connected to the distribution system and behind-the-meter (on customers’ premises).
- Impact of rooftop PV on regional demand, and subsequent challenges it may pose to the network.

[35] The power produced from wind farms is dependent on the wind flowing at any given time. Sudden and frequent changes in wind can produce large changes in generation.

High wind snapshot

The high wind snapshot captures the conditions when the Victorian network is subject to high wind generation output. Key summary indicators are provided in Table 5.

Operational demand at the time of the snapshot is neither high enough to cause risk of thermal overload, nor low enough to develop the potential of over-voltages. The system has comparable inertia to other snapshots, and there were no system security incidents.

This highlights that there was no significant visible stress on the network during these conditions.

Table 5 High wind snapshot summary

	High wind snapshot
Date and time	14:59:47 on 22 February 2017
Operational demand at time of snapshot	5,997 MW
Sum of Victorian loads at time of snapshot	5,847 MW
Sum of Victorian generation at time of snapshot	6,874 MW
Sum of Victorian capacity at time of snapshot	7,627 MW
Temperature in Melbourne	31.9 °C
Percentage renewable generation Wind Hydro Rooftop PV	 1,011 MW 627 MW 597 MW
System security (N-1)	No system normal or contingency overloads

The level of renewable generation penetration is expected to increase in Victoria, as the generation mix changes due to VRET. AEMO has identified a number of emerging technical challenges and uncertainties associated with the changing generation mix, and will continue to monitor the performance of the network during periods of high renewable generation. Details on the emerging challenges are presented in Section 4.3.

Reverse flows

The frequency and magnitude of reverse power flows has increased in Victoria over the past few years. The two 220/66 kV Terang transformers have been identified as experiencing the largest duration of reverse flows in Victoria over the 2016–17 year. Table 6 outlines the number of hours that reverse flows occurred through these transformers, categorised into seasons.

Table 6 Times reverse flows occurred through Terang

Year	Autumn	Winter	Spring	Summer	Total
2013–14	13 hrs	4.5 hrs	9.5 hrs	0 hrs	27 hrs
2014–15	8.5 hrs	0 hrs	7.5 hrs	1 hrs	17 hrs
2015–16	25.5 hrs	11.5 hrs	6.5 hrs	5.5 hrs	49 hrs
2016–17	45 hrs	8 hrs	45.5 hrs	6 hrs	104.5 hrs

The table highlights the increasing frequency of reverse flows, a trend that will continue to grow and appear in other areas as more Distributed Energy Resources (DER) connect to the network. Currently, reverse flows have not resulted in any issues in the DSN, but this trend of increasing reverse flows will create a more complex network to operate, and may require re-optimisation of asset control schemes to ensure secure and reliable operation.

Strong coordination between TNSPs and DNSPs will be important to monitor and manage these reverse flows and other effects of increased DER.

Rooftop photovoltaic (PV)

Rooftop PV has the ability to reduce the apparent operational demand, allowing it to lessen peak demand and potentially further decrease the minimum demand seen in the network.

Historically, rooftop PV has impacted demand during daylight hours between 08:00 and 17:00. It has not impacted minimum demand, which has historically occurred outside of daylight hours, between the hours of 02:00 and 05:00. AEMO's latest forecasts are projecting the time of minimum demand to move from overnight to midday by 2022 in Victoria[36], mostly driven by the increasing penetration of rooftop PV. This would have the consequence of exacerbating network issues that occur during minimum demand periods, outlined in more detail in Section 2.2.2 and Section 3.5.

AEMO will continue to monitor this area, to ensure changes to minimum demand periods do not adversely impact network operations.

2.6.2 Generator retirements

The changing generation mix has begun to materially change flows on the Victorian DSN, following the closure of the last Hazelwood Power Station unit on 29 March 2017. The future of the remaining coal-fired generators in Victoria is uncertain, as the power system transitions to a low-carbon future.

The Hazelwood retirement has removed 1,600 MW of brown coal generation capacity, resulting in the following immediate outcomes:

- Reduction in dispatchable base load generation capacity available within Victoria to supply demand. Refer to AEMO's market insight report on Victoria's supply outlook[37] for further detail.
- Reduction in reactive power capability available to control network voltages during minimum demand periods. The challenges associated with maintaining voltage within operating limits during periods of minimum demand is investigated in Section 3.5.

In the longer term, the deployment of up to 5,400 MW of new large-scale renewable generation by 2025, incentivised by the VRET, will impact the utilisation of particular DSN paths and interconnector flows. This is explored Section 3.7. Increasing penetration of renewable generation may justify investment in additional interconnection capacity between Victoria and other NEM regions, examined further in Section 4.2.2.

[36] AEMO, 2017 *Electricity Forecasting Insights* report. Available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Electricity-Forecasting-Report.

[37] AEMO. *Market insight report – Victoria's supply outlook*, November 2016. Available at: https://aemo.com.au/Media-Centre/AEMO-Market-insight-report-Victorias-supply-outlook.

CHAPTER 3. NETWORK DEVELOPMENT

This chapter describes forecast DSN limitations[38] that are expected to appear over the next 10 years.

Key insights of this chapter

- **Increased network capacity is needed in wind and solar resource rich areas.** There is a need to increase network capacity in western Victoria (which is rich in wind and solar resources), to facilitate the transport of projected additional renewable generation incentivised by the VRET to demand centres within Victoria. AEMO is progressing the Western Victoria Renewable Integration Regulatory Investment Test for Transmission (RIT-T), which seeks to increase the capability of the western Victoria power system, and reduce congestion of projected new generation in that region.
- **Stronger interconnection is needed between Victoria and New South Wales.** There is an emerging need to augment the interconnection between Victoria and New South Wales to allow sharing of excess generation between regions of the NEM.
- **Declining minimum demand is driving the need for additional reactive power support.** **I**ncreasing penetration of rooftop PV is projected to drive a rapid reduction in minimum demand, which can lead to high voltages outside safe operating limits. The 2017 VAPR analysis identifies the need for additional reactive power support to maintain voltages within operating limits.

3.1 Methodology

3.1.1 DSN augmentation planning approach

To identify network augmentation needs, AEMO first investigates transmission network limitations by:

- Reviewing historical network performance over the previous year and the periods that known constraints were binding.
- Reviewing future network performance under a range of demand and generation scenarios considering government policy and economic growth projections.

For any major transmission limitations identified, AEMO performs an exploratory study, using high level market modelling to identify the market benefits of relieving the transmission limitations.

Appendix C has more information on AEMO's transmission network limitation review approach.

If net market benefits are identified as likely, AEMO initiates a pre-feasibility study, using detailed market modelling to assess the benefits from credible augmentation options. This pre-feasibility study may lead to a RIT-T.

This analysis provides signals for potential network and non-network development opportunities, such as localised generation or demand response.

Further detail on the DSN planning methodology can be found in AEMO's *Victorian Electricity Planning Approach*.[39]

3.1.2 Scenarios considered

The scenarios considered in this report align with AEMO's latest *National Energy Forecasting Report* (NEFR). The demand scenarios consider sensitivities to factors such as population and economic

[38] DSN limitations represent network capacity shortfalls which impose constraints on power transfer or result in inability to meet the network performance requirements set out in NER or other relevant legislation or regulations.
[39] AEMO. *Victorian Electricity Planning Approach*, 2016. Available at: http://www.aemo.com.au/Electricity/Policies-and-Procedures/Planning/Victorian-Electricity-Planning-Approach.

growth, technology uptake, and consumer confidence. The scenarios also consider potential changes to the generation mix to meet the VRET[40] and the Federal Government's Large-scale Renewable Energy Target (LRET).

Specifically, the VAPR considers the following scenarios over a 10-year outlook:

- Neutral Demand scenario. This assumes operational consumption increases in line with the latest *National Electricity Forecasting Report* (NEFR) Neutral scenario, and a generation expansion and retirement plan in line with the latest *National Transmission Network Development Plan (*NTNDP) generation outlook for the Neutral Demand scenario.
- Weak Demand scenario. This assumes operational consumption in line with the latest NEFR Weak scenario and a generation expansion and retirement plan in line with the latest NTNDP generation outlook for the Low Grid Demand scenario. Compared to the Neutral Demand scenario, this generation expansion and retirement plan has less renewable generator connection and more retirement of coal-fired generation within the next 10 years.

3.2 Completed projects and retirements

3.2.1 Network upgrades

The following projects have been completed since the 2016 VAPR:

- Heywood Interconnector upgrade.
  - The third Heywood 500/275 kV transformer and 500 kV bus-tie were commissioned in December 2015. This project also included supporting augmentations in South Australia[41], which were completed in August 2016. The combination of these works was expected to increase the Heywood Interconnector transfer capacity from 460 MW to 650 MW.[42]
  - Following completion of these works, a program to progressively test the operation of the Heywood interconnection at higher power transfers commenced. On 28 September 2016, when the South Australia Black System[43] occurred, the maximum transfer allowed from Victoria to South Australia was limited to 600 MW and from South Australia to Victoria was 500 MW.
  - AEMO's analysis of the South Australia Black System event identified a potential transient stability issue at high Victoria to South Australia transfer and high levels of wind generation in South Australia. The transient stability transfer limit over the Heywood Interconnector is being reviewed, and in the interim, the current limits of 600 MW (Victoria to South Australia) and 500 MW (South Australia to Victoria) remain in place.[44]
- Brunswick terminal station 66 kV connection.
  - The overall capacity of Brunswick Terminal Station has increased following the installation of a new 66 kV supply comprising three 225 MVA 220/66 kV transformers, completed in April 2017.
- Ararat terminal station.
  - This new terminal station facilitating the connection of Ararat Wind farm was completed in July 2016.
- Ballarat – Horsham 66 kV bus splitting control scheme.
  - A limitation associated with the ability of the Ballarat – Horsham 66 kV line to service parts of regional Victoria was addressed by an automatic bus splitting control scheme at Buangor 66 kV

[40] The VRET targets 25% and 40% of energy consumed in Victoria to be met by renewable generation by 2020 and 2025 respectively.
[41] Includes installation of 50% series compensation on the Tailem Bend – South East 275 kV lines in SA and reconfiguration of the 132 kV transmission lines running in parallel with the Tailem Bend – South East 275 kV lines.
[42] AEMO. Interconnector capabilities. Available at: http://www.aemo.com.au/Electricity/Resources/Reports-and-Documents/Network-Operations/Interconnector-Capabilities.
[43] AEMO, South Australia region Black System event report. Available at: https://www.aemo.com.au/Media-Centre/AEMO-publishes-final-report-into-the-South-Australian-state-wide-power-outage.
[44] AEMO. Update inter-network testing and transfer limit – Heywood interconnector. Available at: http://www.aemo.com.au/Market-Notices?currentFilter=&sortOrder=&searchString=56893.

switching station. The scheme, which was completed in December 2016, has improved export capability to New South Wales and South Australia, and facilitates renewable generation export out of north-west Victoria.

- Interconnector Emergency Control Scheme (IECS).
  - The IECS provides high speed automatic tripping of selected loads to prevent wider disruption with potential for larger impact. As part of the AusNet Services Network Capability Incentive Parameter Action Plan (NCIPAP) for 2014–2017[45], an IECS has been installed to meet the NER S5.1.8 requirements. This IECS will automatically shed selected Victorian customer loads to prevent a Victorian power system separation from New South Wales following simultaneous loss of multiple transmission lines around Dederang, including the Victoria – New South Wales interconnector. The load shed will be restored quickly as soon as the power system becomes stable after the event, subject to meeting other network performance requirements set out in the Rules. A Victorian separation event could otherwise trigger under frequency load shedding (UFLS), which may otherwise result in much larger and prolonged loss of customer load.

3.2.2 New generator connection

Ararat Wind Farm successfully connected to the Victorian DSN in August 2016.

3.2.3 Retirements

The synchronous condensers at Fisherman's Bend, Brooklyn, and Templestowe were fully decommissioned by September 2016.

Hazelwood Power Station closed in March 2017.

3.3 Future projects and opportunities

This section presents findings from AEMO's annual planning review of transmission network limitations in Victoria, as well as future projects and retirements.

Information on committed future terminal station projects for connecting load or generation is also presented in this section. This is supported by AEMO's policy and guidelines for establishing new terminal stations in Victoria.[46]

3.3.1 Potential generation projects

For generator transmission connections in Victoria, AEMO is involved in all stages of the connection process, from pre-feasibility to completion.

For generator distribution connections, the connecting DNSP manages the connection process and is the main point of contact for the connection applicant.

Information on potential generation projects for development over the next 10 years can be found on AEMO's generation information page.[47] Information on AEMO's processes for network connections[48], network augmentations to cater for new generation connections, and requests for network data[49] can be found on AEMO's website.

[45] AER. SP AusNet transmission determination 2014–15 to 2016–17. Available at: https://www.aer.gov.au/system/files/AER%20transmission%20determination%20for%20SP%20AusNet%27s%202014-17%20regulatory%20control%20period%20-%2031%20January%202014.pdf.

[46] AEMO. *Guidelines for Establishing Terminal Stations in Victoria, 2011*. Available at: http://www.aemo.com.au/~/media/Files/Other/network_connections/0174-0018%20pdf.ashx.

[47] AEMO. Generation Information. Available at: http://www.aemo.com.au/Electricity/Planning/Related-Information/Generation-Information.

[48] AEMO. Network Connections. Available at: http://www.aemo.com.au/Electricity/Network-Connections.

[49] AEMO. *Policy on provision of network data*. Available at: http://www.aemo.com.au/Electricity/Policies-and-Procedures/Planning/Policy-on-Provision-of-Network-Data.

3.3.2 Committed transmission network projects and retirements

The following projects meet the criteria for committed projects, having advanced to the point where proponents have secured land and planning approvals, entered into contracts for finance, and either started construction or set a firm date:

- Additional Ballarat – Moorabool 220 kV transmission line.
  - This circuit was proposed as the second stage of the preferred option from the Regional Victorian Thermal Capacity RIT-T and is scheduled for completion in June 2017.[50]
- Deer Park terminal station.
  - AEMO, Jemena, and Powercor identified the need for a new terminal station at Deer Park to address limitations at terminal stations servicing Jemena and Powercor's distribution networks in the western Melbourne metropolitan area. The scheduled completion date is November 2017.[51]

3.4 Current development opportunities

Western Victoria Regulatory Investment Test for Transmission (RIT-T)

The Western Victoria Renewable Integration RIT-T seeks to increase the capability of the western Victoria power system, and reduce congestion of projected new generation in that region. See the Project Specification Consultation Report (PSCR) of this RIT-T for more information.[52] Further detail on this RIT-T is also in Section 4.2.1.

South Australian Energy Transformation RIT-T

ElectraNet is exploring network and non-network options that can facilitate South Australia's energy transformation through the South Australian Energy Transformation RIT-T.[53]

AEMO is engaged in joint planning with ElectraNet investigating the feasibility of one of the options being considered, a potential new interconnection between Victoria and South Australia.

3.5 Emerging development opportunities

The VAPR identifies opportunities to address transmission network limitations, where credible solutions are likely to deliver positive net market benefits within the next 10 years.

The following emerging development opportunities have been identified:

- Maintain voltages within operational limits during minimum demand periods.
- Transfer surplus generation out of Victoria to New South Wales following the installation of projected VRET generation and the relief of congestion in western Victoria.
- Improve New South Wales to Victoria import capability.

[50] AEMO. *Regional Victorian Thermal Capacity Upgrade*. Available at: http://www.aemo.com.au/Electricity/Planning/Regulatory-Investment-Tests-for-Transmission/Regional-Victorian-Thermal-Capacity-Upgrade.

[51] Jemena. Powercor, Jemena and AEMO joint regulatory test report. Available at: https://jemena.com.au/industry/electricity/network-planning/western-metropolitan-melbourne-transmission-connec.

[52] AEMO. Regulatory Investment Tests for Transmission. 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.

[53] ElectraNet. South Australian Energy Transformation RIT-T. Available at: https://www.electranet.com.au/projects/south-australian-energy-transformation/.

Maintain voltages within operational limits during minimum demand periods

Impact on transmission performance

High voltages due to lightly loaded transmission lines in the South-West Corridor around Geelong, Keilor, Portland, and Moorabool have been observed during minimum demand periods.

The retirement of Hazelwood Power Station has also reduced the reactive power capability available to control network voltages during minimum demand periods.

AEMO successfully managed the high voltages using temporary operational measures, such as de-energising 500 kV line(s). While these operational measures can keep voltages within operating limits, they can also potentially constrain generation, incurring a market impact. The de-energisation of 500 kV lines also increases operational risks due to reduced availability of transmission infrastructure.

AEMO is forecasting a rapid reduction of Victorian minimum demand. The time of minimum demand is projected to move from overnight to midday by 2022 in Victoria, mostly driven by the increasing penetration of rooftop PV. This will further reduce loading on already lightly loaded lines (during minimum demand periods), exacerbating the high voltages.

Forecast market benefit

The 2017 VAPR analysis shows that the forecast market benefit from avoiding 500 kV line de-energisation during minimum demand periods is approximately $7.0 million over the next 40 years under the Neutral Demand scenario, and $26 million under the Weak Demand scenario.

Development options considered

An operational option being explored is to switch off capacitor banks within the distribution network in Victoria which are normally in service during minimum demand periods:

- The 2017 VAPR analysis, based on historical snapshots, indicates that switching off 200 MVAr distributed capacitor banks can reduce additional absorbing reactive power requirements by approximately 100 MVAr.
- AEMO is working with Victorian DNSPs to identify the exact number of distribution capacitor banks which can be switched off, and the arrangements required to implement this operational option on an ongoing basis.

Generator voltage control will also be used to optimise the voltage profiles in Victoria.

Possible network augmentation options include:

- The installation of shunt reactors, costing approximately $5 million for one 100 MVAr 220 kV shunt reactor (with a single 220 kV Circuit Breaker).
- The installation of shunt reactors, costing approximately $9 million for one 100 MVAr 500 kV shunt reactor (with a single 500 kV Circuit Breaker).
- The installation of SVCs, costing approximately $21 million for one ±200 MVAr 220 kV SVC (with a single 220 kV Circuit Breaker).
- The installation of SVCs, costing approximately $27 million for one ±200 MVAr 500 kV SVC (with a single 500 kV Circuit Breaker).

AEMO’s 2017 VAPR analysis shows that the required amount of additional reactive power support (absorbing) is approximately 450 MVAr in 2022, increasing to 630 MVAr in 2027.

The options listed above are indicative network options only. Further studies will be conducted to determine the full list of options, including numbers of plant and sizes, as well as their exact locations. This may also include non-network options, such as demand side participation, which can increase the reactive power consumption when required.

Conclusion

The 2017 VAPR analysis shows that the gross market benefits of alleviating this limitation are likely sufficient to justify augmentation.

AEMO is assessing in more detail if additional reactive power support (absorbing) can be justified economically, considering all operational measures. If it is justifiable, AEMO will commence a project to identify and pursue the preferred option for the provision of additional reactive power support to maintain voltage within operational limits.

Improve Victoria to New South Wales export capability

The 2016 VAPR assessment of export capability to New South Wales concluded that the benefit of increasing Victoria to New South Wales export capability was marginally lower than the augmentation cost, and that this assessment was sensitive to assumptions around the future of brown coal generation in Victoria and what would replace it.

Since the 2016 VAPR, Hazelwood Power Station has retired and the VRET has been announced. This significantly changes the future generation mix in Victoria, and the 2017 VAPR has reassessed the export capability to New South Wales considering these changes.

Impact on transmission performance

Export capability from Victoria to New South Wales is frequently limited by thermal capacity limitations on the South Morang F2 transformer and South Morang – Dederang 330 kV lines, and a transient stability limitation. These limitations will constrain generation within Victoria during times of high Victoria to New South Wales export.

Forecast market benefit

The forecast market benefit of relieving the limitations impacting Victoria to New South Wales export is approximately $170 million over the next 40 years under the Neutral Demand scenario, and $127 million under the Weak Demand scenario. The benefit comes from allowing New South Wales and Queensland customers increased use of lower cost generation from Victoria. South Australian customers will also benefit, because this augmentation also increases the Victoria to South Australia export limit.

The forecast market benefits are higher under the Neutral Demand scenario, which has more surplus generation in Victoria compared to the Weak Demand scenario. The Neutral Demand scenario considers more new renewable generation uptake and less coal-fired generation retirement within the next 10 years. The assessment also shows greater market benefits being realised after the VRET target has been met around 2025.

The market benefits were calculated assuming that all limitations within the western Victoria areas would be fully removed by the preferred option to be identified by the Western Victoria Renewable Integration RIT-T. As such, the market benefits calculated represent the upper bound of market benefits achievable, and are sensitive to the preferred option to be identified by the Western Victoria Renewable Integration RIT-T.

Development options considered

Any project to improve Victoria to New South Wales export capability will need to collectively address all three limitations mentioned above, as they all play a similar role in limiting the transfer from Victoria to New South Wales.

The following three augmentation options may be considered:

1. Installation of a new 500/330 kV transformer at South Morang.
2. Uprating of the South Morang – Dederang 330 kV lines by conductor re-tensioning.
3. Increasing the transient export limit, through network or non-network solutions.

The projected total cost of these augmentation options is approximately $73.5 million. However, if more substantial upgrades or a new circuit were to be required for the South Morang – Dederang 330 kV, this cost could increase.

The augmentation options listed above only present one possible set of options. There may be other options which can also increase the Victoria to New South Wales transfer limit. These options should be treated as indicative only, and a RIT-T will be required to determine the preferred set of options.

Conclusion

The 2017 VAPR analysis shows that the gross market benefits of alleviating the three limitations are likely sufficient to justify augmentations, under both Neutral Demand and Weak Demand scenarios.

AEMO will commence a pre-feasibility study within the next 12 months on the need to improve Victoria to New South Wales export capability, considering the preferred options from the Western Victoria Renewable Integration RIT-T and the South Australia Energy Transform RIT-T once they become available. This pre-feasibility study will also consider latest developments, including outcomes from the Snowy 2.0 feasibility study[54], the South Australian energy plan[55], and the Victorian Government's storage initiative.[56] This pre-feasibility study may trigger a RIT-T to identify the preferred option for increasing the Victoria to New South Wales transfer limit.

Improve New South Wales to Victoria import capability

Impact on transmission performance

Import capability from New South Wales to Victoria is limited by thermal limitations on the Murray – Dederang 330 kV lines, the South Morang – Dederang 330 kV lines, and the Dederang – Mount Beauty – Eildon – Thomastown 220 kV transmission path, as well as a voltage stability limitation. Any increase in this import capacity will help support Victoria during high demand periods. This will likely be required in the short to medium term, until VRET generation is installed, to help address the loss in dispatchable baseload generation capacity within Victoria following the closure of Hazelwood Power Station.

Development options considered

AEMO is considering network and non-network options. These include (but are not limited to) the following possible options, which can be implemented within a short lead time, to increase import capability for the short to medium term:

1. Implement an automatic load shedding scheme to allow for operating the Murray – Dederang 330 kV lines to a higher rating. This measure will increase the thermal import limit to Victoria by about 200 MW.
2. Procure network support services to increase the voltage stability import limit to Victoria from New South Wales. This service may involve the provision of additional reactive support (generating).
3. Increase the transfer capability by installing wind monitoring facilities on the Dederang – Mount Beauty – Eildon – Thomastown 220 kV lines.
4. Implement an automatic load shedding scheme to allow for operating the Dederang – Mount Beauty – Eildon – Thomastown 220 kV lines to a higher rating.

Conclusion

The 2017 VAPR analysis shows that minor augmentation options with relatively low cost and short lead time are available for increasing the import capability from New South Wales to Victoria. AEMO will commence a pre-feasibility study, including a market benefit assessment, on these augmentation

[54] Snowy Hydro. Snowy 2.0 feasibility study. Available at: http://www.snowyhydro.com.au/our-scheme/snowy20/.
[55] South Australian Government. SA Energy Plan. Available at: http://ourenergyplan.sa.gov.au/.
[56] Victorian Government. Batteries and energy storage. Available at: https://www.energy.vic.gov.au/batteries-and-energy-storage.

options within the next 12 months, and may pursue options which can be economically justified based on the outcome of the market benefit assessment. This pre-feasibility study will also consider latest developments impacting the generation mix in the short to medium term, including outcomes from the Snowy 2.0 feasibility study[57], the South Australian energy plan[58], and the Victorian Government's storage initiative.[59]

3.6 Monitored transmission limitations

AEMO, through the VAPR analysis, continues to monitor transmission network limitations that may result in supply interruptions or constrain generation periodically, but for which there is currently no known credible solution likely to deliver positive net market benefits.

The full list of monitored transmission limitations can be found in Appendix A. These limitations are not expected to significantly impact on the electricity market within the next one, three, or five years, but may have an impact on the market after this time, depending on changes in generation location and increases in import export, or demand growths.

AEMO invites stakeholders to discuss any monitored transmission limitations where they consider a solution might deliver net market benefits. Otherwise, AEMO does not plan to undertake further detailed assessment on these limitations within the next 12 months, but will continue to monitor triggering conditions.

Relieve Moorabool – Geelong and Geelong – Keilor 220 kV line thermal limitations

Impact on transmission performance

The Western Victoria Renewable Integration RIT-T will seek to increase capacity and relieve transmission limitations within western Victoria. To allow additional VRET renewable generation to be transferred from this region to load centres elsewhere in Victoria, the capacity of the Moorabool – Geelong and Geelong – Keilor 220 kV lines may need to be increased. The timing and extent of any potential constraint is sensitive to the amount and location of the VRET generation, as well as the preferred option of the Western Victoria Renewable Integration RIT-T.

Forecast market benefit

The forecast market benefit of relieving the Moorabool – Geelong and Geelong – Keilor 220 kV line thermal limitations is approximately $2 million over the next 40 years under the Neutral Demand scenario, and less than $1 million under the Weak Demand scenario.

The market benefits were calculated assuming that all limitations within the western Victoria areas would be fully removed by the preferred option to be identified by the Western Victoria Renewable Integration RIT-T. As such, the market benefits calculated represent the upper bound of market benefits achievable, and are sensitive to the preferred option to be identified by the Western Victoria Renewable Integration RIT-T.

Development options considered

The following network development option could address these limitations:

1. Installing a new single circuit Moorabool – Geelong 220 kV line with a rating of approximately 800 MVA at 35ºC, with an estimated cost of $11 million, and replacing the existing Geelong – Keilor No. 1 and No. 3 220 kV lines with a new double circuit lines rated at 700 MVA at 35ºC, with an estimated cost of $74 million.

[57] Snowy Hydro. Snowy 2.0 feasibility study. Available at: http://www.snowyhydro.com.au/our-scheme/snowy20/.
[58] South Australian Government. SA Energy Plan. Available at: http://ourenergyplan.sa.gov.au/.
[59] Victorian Government. Batteries and energy storage. Available at: https://www.energy.vic.gov.au/batteries-and-energy-storage.

There may be other options to address these limitations. The option presented should be treated as indicative only, and a RIT-T will be required to determine the preferred option.

Conclusion

The 2017 VAPR analysis shows that gross market benefits are insufficient for investment to address the Moorabool – Geelong and Geelong – Keilor 220 kV line thermal limitations. AEMO will monitor these limitations, taking into consideration the preferred option of the Western Victoria Renewable Integration RIT-T and the level of VRET generation connection.

3.7 Asset renewal and utilisation

AusNet Services' Asset Renewal Plan, containing the current list of asset renewal projects planned for the next 10-year period, is on AEMO's website (see Section 1.1).

The 2017 VAPR assesses the impact of anticipated future change in energy flows in Victoria, associated with relocation of energy production, on utilisation[60] of transformers at Keilor and 500 kV transmission lines in the Latrobe Valley. These utilisation studies forecast the annual loading profiles of the transformers and 500 kV transmission lines over the next 10 years, indicating the long-term needs for these assets.

The change is mainly due to the high level of new renewable generation expected to connect in western Victoria, combined with the Hazelwood Power Station shutdown.

3.7.1 Long-term need for Keilor 500/220 kV transformers

The three 500/220 kV transformers at Keilor Terminal Station are expected to reach the end of their service life by 2025. This presents an opportunity to optimise all the 500/220 kV Victorian transformers and associated bus configuration which form part of the transmission path supplying load centres within the Greater Melbourne and Geelong area.

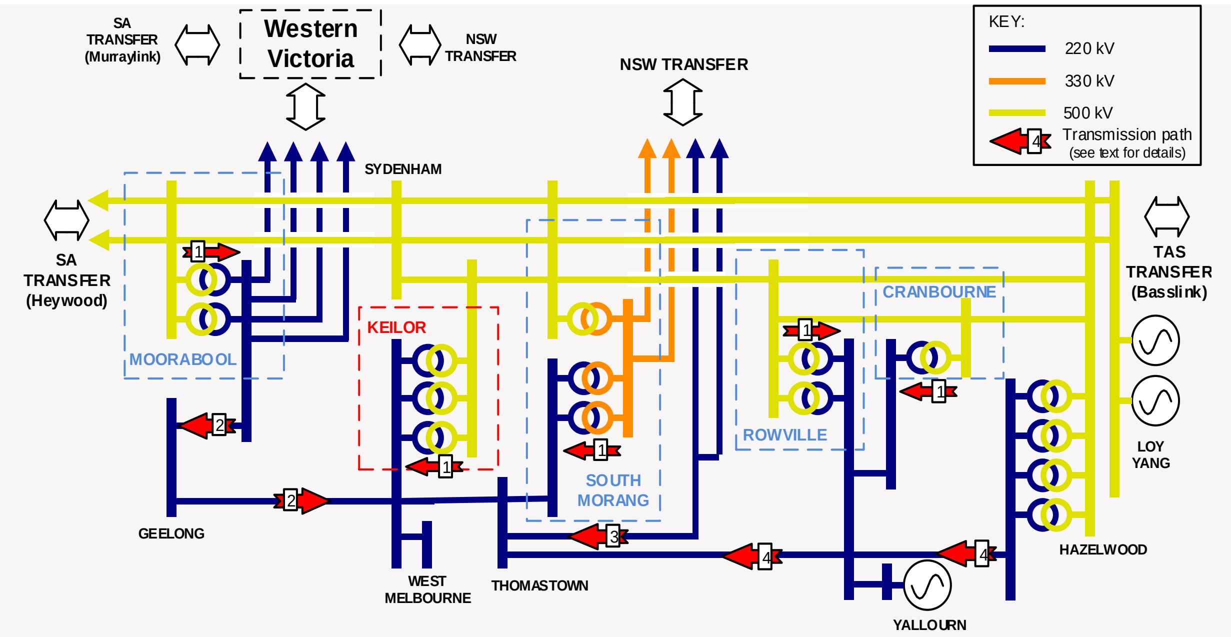
As illustrated in Figure 4, the metropolitan Melbourne load centres are supplied by the following transmission paths:

1. The 500 kV network via the 500/220 kV transformation at Moorabool, Keilor, South Morang, Rowville, and Cranbourne.
2. Moorabool – Geelong – Keilor 220 kV lines.[61]
3. Dederang – Mt Beauty – Eildon – Thomastown 220 kV lines.
4. Latrobe Valley (Yallourn and Hazelwood) – Rowville 220 kV lines.

[60] This assessment considered both system normal (N) when all DSN infrastructure was in service and single outage (N-1) conditions when one component of DSN infrastructure was out of service.

[61] The flow is mainly westward at present, but is expected to become eastward after a large amount of renewable generation connected to the western Victoria areas due to the VRET.

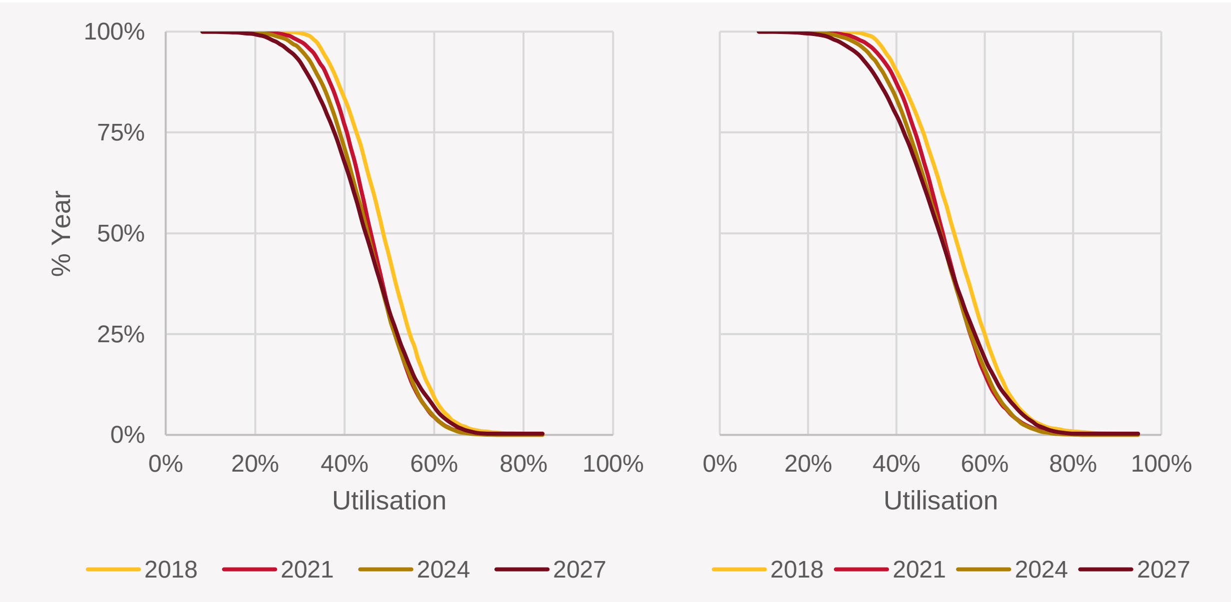
Figure 4 Major transmission paths supplying load centres within Greater Melbourne and Geelong area



During peak demand periods, generation at Newport, Laverton North, and Somerton would also be dispatched if necessary to supply a significant portion of the Melbourne demand.

Figure 5 presents Keilor transformer's annual loading profiles from the utilisation studies, which show no significant change in the loading profile for the Keilor transformers over the next 10 years, with utilisation[62] of the transformers projected to slightly decrease towards the end of the outlook period. Studies also concluded that in the 10-year outlook, all Keilor transformers will be loaded up to 84% of their rated capacity under system normal condition and 94% under N-1 condition.

Figure 5 Loading profiles[63] for Keilor A3 transformer under system normal (left) and N-1 (right)



[62] Utilisation is defined as the % power loading, based on rating of the asset. An utilisation greater than 100% indicates a potential overload.
[63] A loading profile curve plots the utilisation of an asset against the time (in % of a year) that the utilisation is greater than that value.

Possible options for replacing the 500/220 kV transformer include:

- Like for like replacement of all three Keilor transformers.
- Like for like replacement of the existing three Keilor transformers with only two Keilor transformers.
- Replacement of the existing three Keilor transformers with two higher rated transformers (1000 MVA continuous rating) of lower impedance (18%). One of the additional benefits of this option is standardising the 500kV/220 kV transformers in Victoria and thus reducing the need for procuring site specific spare transformers.

AEMO has conducted a power system study to assess the benefits of optimised configurations at Keilor terminal station when the existing 500/220 kV transformers reach their end of serviced life, that is, the option of replacing only two of the existing 500/220 kV transformers at Keilor terminal station. The study indicates this replacement:

- Will not cause transformer capacity shortage at Keilor, because the capacity of the remaining 500/220 kV transformers will be sufficient for both system normal and outage of one of the remaining transformers.[64]
- Will increase thermal loadings on other transmission paths, contributing to DSN component overloading under certain operating conditions.
  - Replacing only the A2 and A4 transformers will significantly increase loading on remaining Victorian 500/220 kV transformers which are already critically loaded and may result in transformers overloading.
  - Replacing only the A2 and A4 transformers will result in increased congestion on 220 kV lines connecting to South Morang and Geelong terminal stations.
  - Replacing only the A3 and A4 transformers will increase the loading of remaining 500/220 kV transformers which are already critically loaded, but to a lesser extent than the removal of the A3 transformer.
  - Replacing only the A3 and A4 transformers will result in increased congestion on the Moorabool – Geelong – Keilor 220 kV lines.

Further detailed assessment of this option, together with all other possible solutions including impact of DER, will need to be conducted to determine the option which provides the highest net market benefit.

AEMO will carry out joint planning studies with AusNet Services, including a market benefit assessment, to determine the preferred option for replacing the existing 500/220 kV transformers at Keilor.

3.7.2 Hazelwood to South Morang 500 kV transmission path

The high-capacity 500 kV lines west out of Hazelwood Terminal Station[65] are essential for transporting high volumes of energy from the Latrobe Valley and Tasmania via the Basslink interconnector to load centres in Victoria, South Australia, and New South Wales.

The loading profiles for the Hazelwood to South Morang No.1 500 kV line are shown in Figure 6, with the other lines following similar trends. These studies show that the:

- Flows on this transmission path will become more volatile over the next 10 years. Figure 6 shows that in 2018, the lines exceed 20% of their rated capacity for less than 300 hours a year under system normal conditions. By 2027, this is projected to increase to over 2000 hours.
- Lines will be loaded up to 35% of their rated capacity under system normal condition and 48% under N-1 condition.[66]

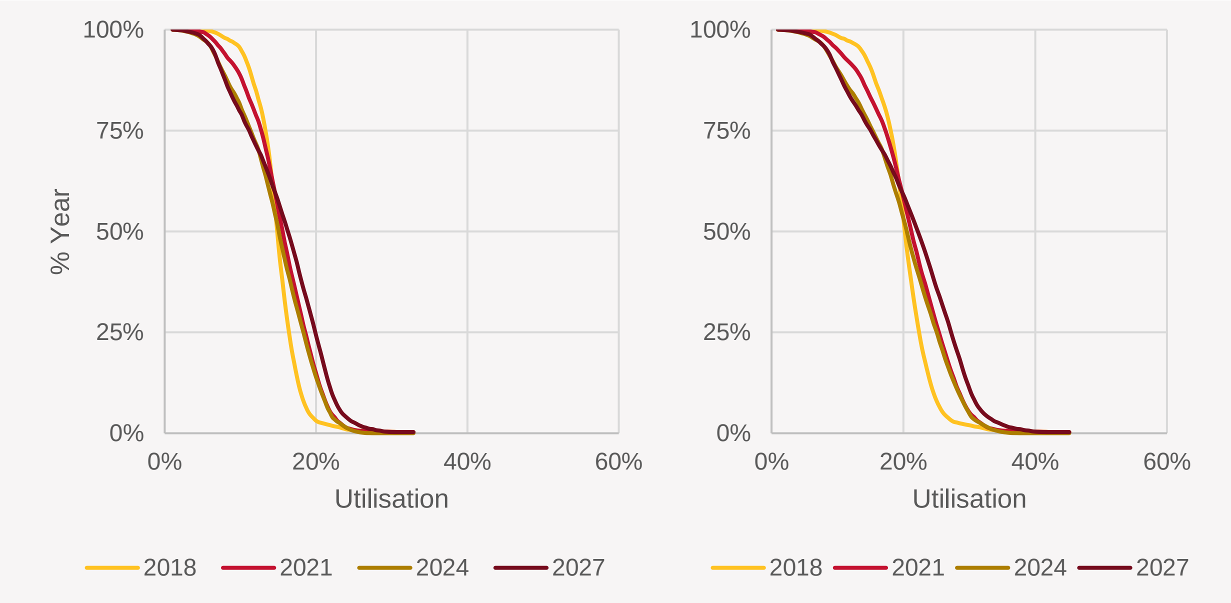
[64] This is based on an assumption that Laverton North and Newport Power Stations will be in service during summer high demand periods.
[65] Hazelwood to South Morang 1 and 2; Hazelwood to Rowville; Hazelwood to Cranbourne; Cranbourne to Rowville, and Rowville to South Morang (see Figure 4).
[66] N-1 refers to single outage conditions when one component of DSN infrastructure is out of service.

The possible causes of this potential volatility in utilisation may include:

- Brown coal generation in the Latrobe Valley acting more as swing generators[67] rather than base load generation in future years, due to the increase in variable generation sources in the state's western grid driven by the VRET.
- A number of key generation projects in Tasmania[68] in the next 10 years, providing low cost energy to the market, resulting in an increase in imports from Tasmania. As the connection point for Tasmania via the Basslink interconnector is on the Latrobe Valley 500 kV system, this will impact the flow on the 500 kV lines.
- Loading on the lines will increase at times when there is an increased need to export to New South Wales and Queensland.

Economic replacement strategies will need to be considered as these lines reach the end of their serviced life, as these studies show an ongoing need for some, if not all, of the 500 kV lines in the west out of Hazelwood Terminal Station.

Figure 6 Loading profiles for the Hazelwood to South Morang No. 1 line under system normal (left) and N-1 (right)



3.8 Distribution planning

In undertaking augmentation planning, AEMO considers DNSP plans for existing and new connection points, and addresses the impact of DNSP plans in its assessment of transmission network limitations.

AEMO addresses the general impact of distribution network modifications (including load changes and network configuration changes) on the DSN by modelling these modifications at connection points. AEMO and DNSPs work together, undertaking joint planning to address connection asset limitations and potential solutions (for example, installing additional transformers at existing connection points or establishing new connection points). This identifies the most efficient solution for both the distribution network and the DSN.

Increasing penetration of DER (including renewable generation) within the distribution network has begun influencing Victorian network flows, as identified in Chapter 2. The level of DER penetration is

[67] The generator that varies its output to fill the gap between base load generation and demand.
[68] AEMO. Generation Information page, available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Generation-information.

expected to increase in future and contribute to more changes in Victorian network flows. AEMO and DNSPs will need to work together, undertaking joint planning to address the impact of changing network flows due to DER. The future role of DER is discussed further in Chapter 4.

Appendix B lists the preferred connection modifications from Victorian DNSPs' *2016 Transmission Connection Planning Report*, and potential DSN impacts and considerations.

3.9 Network Support and Control Ancillary Services

AEMO's 2016 NTNDP NSCAS assessment identified no NSCAS gap in Victoria. Further detail can be found in Chapter 7 of the 2016 NTNDP[69].

[69] AEMO. 2016 NTNDP. Available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Transmission-Network-Development-Plan.

CHAPTER 4. AN EFFICIENT PATHWAY TO A LOW-CARBON FUTURE

Key insights of this chapter

A combination of emissions reductions targets are driving an energy transformation in Australia. In Victoria, the VRET will incentivise the deployment of up to 5,400 MW of new large-scale renewable generation by 2025, representing the most rapid rate of investment the Victorian power system has experienced to date.

To efficiently and securely support this transition, AEMO is proactively investigating:

- **Increasing the network capacity to wind and solar resource rich areas.** Significant investment to augment the western Victorian transmission network will be required to relieve network congestion and facilitate the VRET.
- **Increasing interconnection to other states**. Improving interconnection, and thereby enabling better supply flexibility between regions with ample intermittent generation (increasing the supply-demand balancing area), will become part of a long-term solution to ensure a reliable electricity supply in a low-carbon world. AEMO will commence a pre-feasibility assessment within the next 12 month to upgrade the Victoria – New South Wales interconnector.
- **Holistic end-to-end co-optimised planning.** AEMO is working with the Victorian Government and other stakeholders towards the co-optimised planning of transmission and distribution network infrastructure, generation investment decisions, and other solutions, to enable VRET objectives to be achieved at least cost to consumers.
- **Leveraging the capability of DER.** The use of DER to help maintain the supply-demand balance will become pivotal as behind-the-meter technology flourishes. DER provide opportunities to manage the power system in new ways, particularly when combined with advanced metering and control. If DER uptake is not holistically managed, however, it is likely to have a substantial and unpredictable impact on the power system. AEMO is engaging with DER aggregators to optimise its network planning solutions.

4.1 Background

In June 2016, the Victorian Government announced new renewable energy targets for Victoria (VRET) of 25% by 2020 and 40% by 2025.[70] To achieve these targets, the Victorian Government has proposed that a reverse auction scheme procures up to 5,400 MW of new large-scale renewable energy generation capacity by 2025, additional to the existing 1,265 MW in place today. This deployment will represent the most rapid rate of investment the Victorian power system has experienced to date.

The rapid influx of renewable generator connections in response to the VRET will drive a new era of investment in Victoria, bringing new opportunities for network and non-network investors.

4.2 An efficient pathway to a low-carbon future

A co-ordinated strategy is required to ensure that the VRET can be met with minimal cost to consumers, by efficiently balancing network and generation investment.

AEMO's strategy towards a low-carbon future involves:

- Increasing network capacity to areas with high-quality renewable resources.
- Increasing interconnection to other states.

[70] More information about the VRET is available at: http://www.delwp.vic.gov.au/energy/renewable-energy/victorias-renewable-energy-targets.

- Holistic end-to-end planning from generation to consumer, considering the optimised expansion of distribution and transmission infrastructure, and other solutions.
- Leveraging the capability of demand response and DER.

4.2.1 Increasing network capacity to areas with high-quality renewable resources

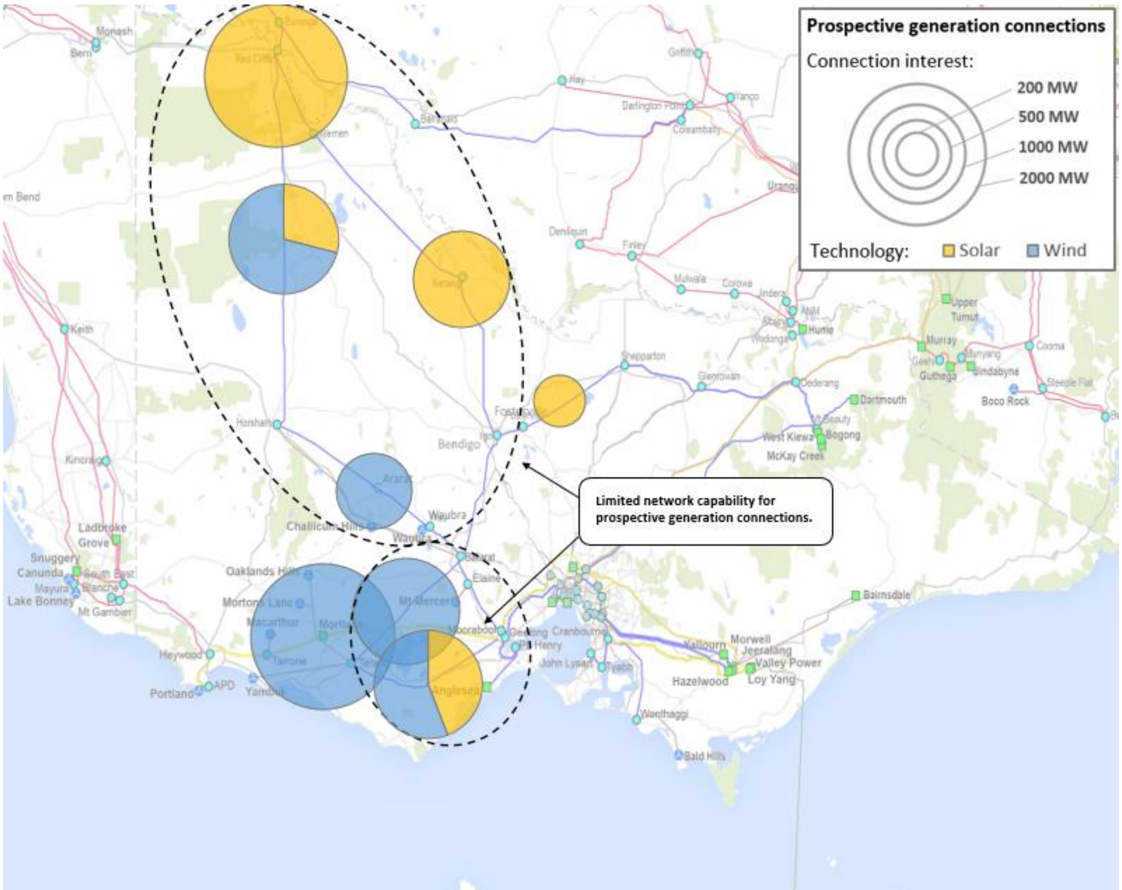
In 1970, Australia's first 500 kV lines were commissioned to transport electricity from the coal-rich Latrobe Valley to load centres in Melbourne. Now, as renewable energy replaces coal, it will become more economic to increase network capacity to high-quality renewable resource areas in western Victoria.

Western Victoria Renewable Integration RIT-T

AEMO has formally initiated a RIT-T to increase the transmission capacity in western Victoria, publishing the Project Specification Consultation Report (PSCR) on 21 April 2017.[71]

The Victorian Government projects that up to 5,400 MW of new renewable generation will be constructed in Victoria as a result of the VRET target. To date, AEMO has received new connection applications and enquiries for over 5,000 MW of new generation capacity in western Victoria. Of this capacity, 80% is proposing to connect to the 66 kV and 220 kV network, with the remainder connecting to the 500 kV network. The figure below shows the approximate volume and location of new connection applications and enquiries in western Victoria, up to March 2017.

Figure 7 New connection applications and enquiries in western Victoria up to March 2017



[71] AEMO. Regulatory Investment Tests for Transmission. 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.

New generators connecting to this part of the Victorian electricity network are expected to be heavily constrained by emerging thermal limitations on the existing 220 kV transmission system, with up to half of their energy output curtailed (depending on proximity to constraints). New generators proposing to connect to the 500 kV transmission network will not be constrained by limitations in western Victoria, but may be constrained by other limitations in the Victorian transmission network.

Without augmentation, thermal transmission limitations in western Victoria may result in a lost generation opportunity of over 1,600 gigawatt hours (GWh) per year. Inefficient generation dispatch could result in higher electricity prices for consumers.

Preliminary market modelling, assuming connection of over 3,000 MW of new renewable generation by 2025[72], shows that removing thermal limitations in western Victoria, either through network augmentation, non-network services, or a mix of both, could result in a gross market benefit of $300 to $500 million over 30 years based on saved generation re-dispatch costs.

Addressing system strength

System strength is an important factor contributing to power system stability under all reasonably possible operating conditions, and can materially impact the way a power system operates. System strength in western Victoria is low due to the electrical distance (network impedance) between local terminal stations in western Victoria and connected synchronous plant.

This limits the amount of non-synchronous generation (like new wind and solar generation) that may be connected to the existing western Victoria network. Without network investments to improve system strength, the potential 3,000 MW of new renewable generation may still be constrained or disconnected, even after investments to improve network thermal capacity have been carried out.

The NER are unclear about who is responsible for maintaining system strength, but the Australian Energy Market Commission (AEMC) has proposed changes to the NER through the System Security Markets Framework Review that will impose this responsibility on Network Service providers (NSPs).[73]

Network investments to improve system strength will facilitate the connection of more inverter-connected generation in western Victoria. AEMO will consider the outcomes of the AEMC's review in the next stage of the Western Victoria Renewable Integration RIT-T.

Investment options

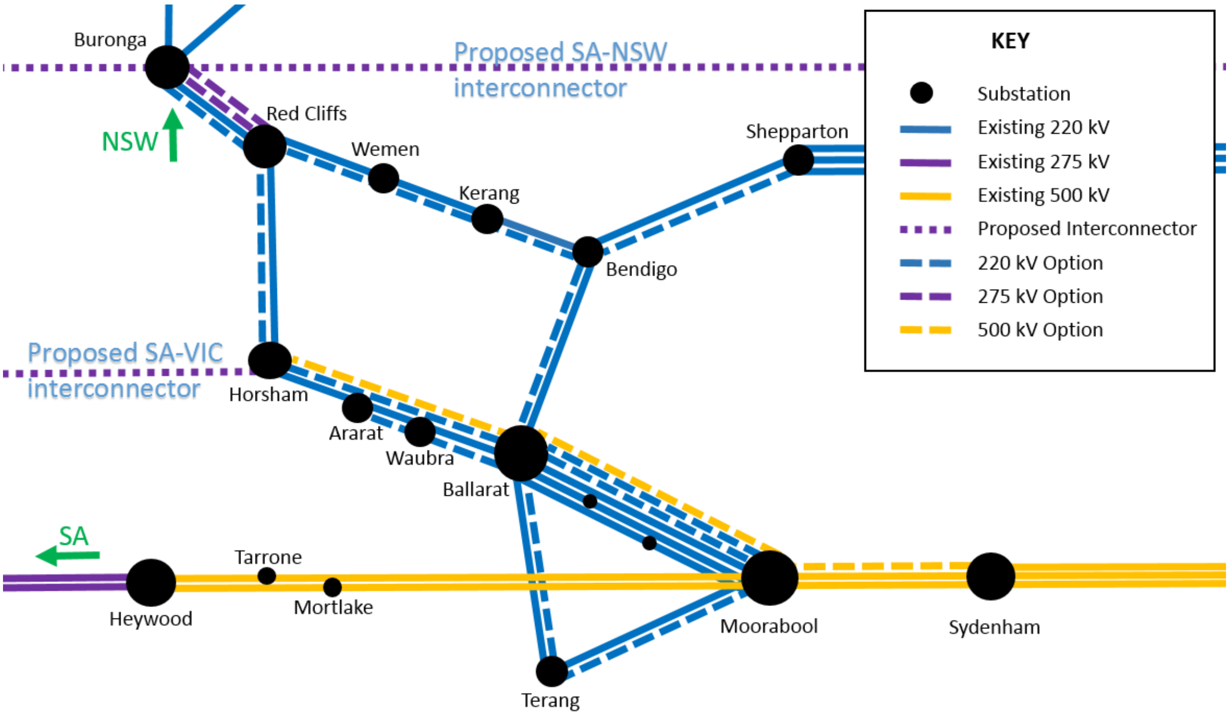
AEMO is considering minor network augmentations, major network reinforcements, and non-network options, to address the identified need.

Figure 8 shows the scope of network investment options being considered (blue, yellow, and purple dashed lines). The preferred option may be influenced by the outcome of ElectraNet's South Australia Energy Transformation RIT-T, which could deliver a new interconnector from South Australia to Victoria or New South Wales (purple dotted lines).

Preliminary studies suggest that a small subset of the 220 kV option will be economic, and that new 500 kV circuits may not deliver sufficient economic benefits to be justified.

[72] Based on the Neutral Demand scenario as outlined in Section 3.1.2.
[73] AEMC. System Security Markets Frameworks Review. Available at: http://www.aemc.gov.au/Major-Pages/System-Security-Review.

Figure 8 Scope of network options being considered



Non-network solutions, including battery storage, DER aggregation, and demand response, can be used to reduce network congestion and maximise the output of renewable generation. These solutions may be economic if they are competitively priced. Non-network solutions can help to maximise the amount of generation produced in areas with an abundance of intermittent generation. Their business case will be most effective when multiple revenue streams can be captured during periods when they are not required to help manage network loading.

AEMO is engaging with both network and non-network providers to deliver an efficient solution to the Western Victoria Renewable Integration RIT-T. The outcome that maximises net market benefits needs to factor in the combined costs of developing new generation where abundant resources are located, and additional infrastructure to transmit the generated electricity.

Next steps for western Victoria

The second stage of the RIT-T process, full options analysis and publication of the Project Assessment Draft Report (PADR), will be within 12 months from 14 July 2017. The preferred option may be a combination of network and non-network components.

AEMO welcomes written submissions on the Western Victoria Renewable Integration PSCR, particularly in relation to the credible network and non-network options presented, and issues addressed in this report. Submissions should be emailed to Planning@aemo.com.au and are due on or before 14 July 2017. Submissions will be published on the AEMO website. If you do not want your submission to be publicly available, please clearly stipulate this at the time of lodgement.

4.2.2 Increasing interconnection capability to other states

As the penetration of intermittent generation increases in each NEM region, the case for increasing interconnection is more likely to be economically justified.

Interconnection allows for better access to geographically diverse resources across the NEM. For example, during periods of low Victorian wind generation, South Australia or New South Wales may have excess wind, or vice versa.

AEMO has conducted an exploratory assessment and identified options for improving Victoria – New South Wales interconnection capability. Refer to Section 3.5 for more details of this assessment.

In addition, AEMO and TransGrid are jointly investigating options for increasing capacity on the Buronga – Red Cliffs 220 kV line, which may also increase the Victoria – New South Wales interconnector capacity.

4.2.3 Holistic end-to-end planning

AEMO is working with the Victorian Government and other stakeholders towards the co-optimised planning of transmission and distribution network infrastructure, generation investment decisions, and other solutions, to enable achievement of VRET objectives at least cost to consumers.

This includes inviting input from alternative service providers on possible non-network solutions for the Western Victoria Renewable Integration RIT-T.

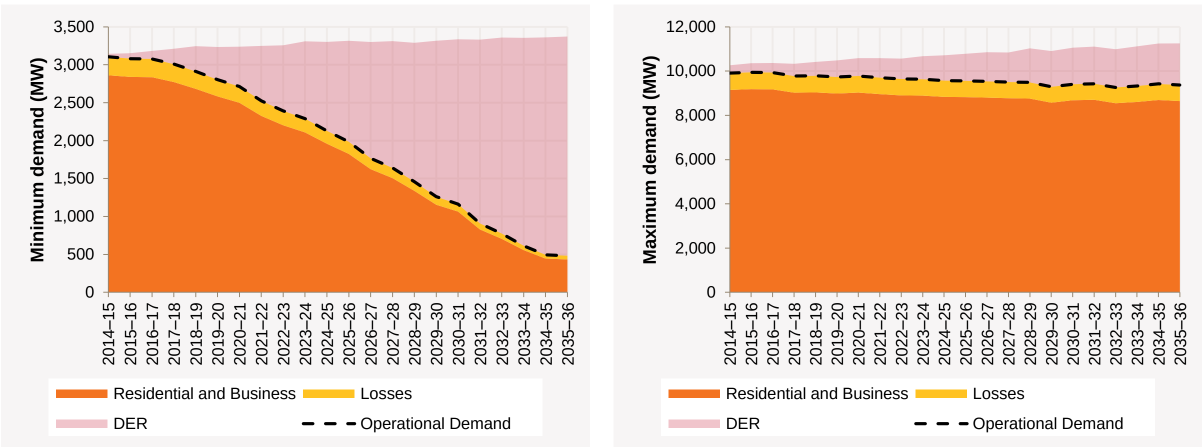
4.2.4 Leveraging the capability of Distributed Energy Resources (DER)

The use of DER to help maintain the supply-demand balance will become pivotal as behind-the-meter technology flourishes.

AEMO's 2016 NTNDP[74] discussed the expected decrease of dispatchable generation across the NEM over the next 20-year period. Also noted was the growing penetration of non-dispatchable rooftop PV, which effectively reduces grid demand to be supplied via transmission and distribution system connected dispatchable generation.

In Victoria, the challenges will be most pronounced during periods of high rooftop PV output. The following figures illustrate the impact of the projected uptake of rooftop PV on Victorian minimum and maximum demand. Over the coming 10-year period, the minimum demand is projected to halve. By 2035–36, DER (largely rooftop PV) is forecast to meet about 85% of the minimum demand. This will challenge existing processes that maintain the supply-demand balance.

Figure 9 Projected Victorian minimum and maximum demand



The uptake of DER will provide an opportunity to manage the power system in new ways, particularly when combined with advanced metering and control. If DER uptake is not holistically managed, however, it is likely to have a substantial and unpredictable impact on the power system.

[74] AEMO. 2016 *National Transmission Network Development Plan* (NTNDP). Available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Transmission-Network-Development-Plan.

Proactively enabling DER

With increasing penetration of demand response and DER, behind-the-meter technologies now impact the transmission network. The NEM, and AEMO's market systems, are adapting to enable aggregated technologies to compete as virtual power plants against traditional power stations. These services will help to defer network investments (thereby reducing electricity prices for consumers), meet energy targets, and ensure peak demand can be met. The appropriate platforms to accommodate these resources must exist to capture their full potential. If managed effectively, DER not only boosts local energy supply but can also provide network support services that subsequently assist in maintaining reliability and security of supply at a lower cost.

AEMO's program to enable DER currently includes:

- Removing energy market barriers for aggregators.
- Removing market ancillary service barriers for DER and demand response.
- Engaging with non-network service providers in network planning.
- Actively engaging with aggregators for emergency reserve.
- Technical review of load models.
- DER and demand response data gathering.

Removing energy market barriers for aggregators

AEMO, in its role as the system operator, is working with the AEMC and the broader industry to contribute to rule change proposals that endeavour to support a secure uptake of DER, including:

- **Five minute settlement**. In May 2016, the AEMC initiated a rule change to reduce the time interval for settlement in the wholesale electricity market from 30 minutes to five minutes.[75] AEMO, in its role as the system operator, has published information to inform the rule change process, and made a submission to the AEMC's directions paper in May 2017. AEMO's submission agreed that settlement and dispatch should be aligned, and offered suggestions to expedite the introduction of five minute settlement, assure success and reduce costs. In the Victorian context, AEMO expects that a five minute settlement will improve the economic case for fast response units such as battery storage.
- **Non-scheduled generation and load in central dispatch.** In May 2016, the AEMC initiated a rule change to require central dispatch participation for large loads (above 30 MW) and small generators (above 5 MW). AEMO supports this rule change proposal and may, in its role as the system operator, require more registered participants (such as small generators and loads) to participate in the central dispatch process in future.

Removing market ancillary service barriers for DER and demand response

In November 2016, the AEMC amended the NER, creating a new classification of market participant, a Market Ancillary Service Provider (MASP).[76] Until 1 July 2017, when the rule comes into effect, market ancillary services can only be provided by registered energy market participants.

AEMO, in its role as the system operator, is implementing these changes, which will allow demand response and DER aggregators to participate in ancillary service markets.[77] From 1 July 2017, demand response and DER aggregators will be able to supply frequency control ancillary services (FCAS). In the Victorian context, removing barriers for DER and demand response could increase competition between service providers and reduce the costs of such services to electricity consumers.

[75] AEMC. Five Minute Settlement. Available at: http://www.aemc.gov.au/Rule-Changes/Five-Minute-Settlement#.
[76] AEMC. Demand Response Mechanism and Ancillary Services Unbundling. Available at: http://www.aemc.gov.au/Rule-Changes/Demand-Response-Mechanism#.
[77] AEMO. Amendment of the Market Ancillary Service Specification. Available at: https://www.aemo.com.au/Stakeholder-Consultation/Consultations/Amendment-Of-The-Market-Ancillary-Service-Specification.

Engaging with non-network service providers in network planning

AEMO is actively engaging with non-network service providers in the Western Victoria Renewable Integration RIT-T (see Section 4.2.1). AEMO is also working with policy makers and industry to gain better operational visibility of these technologies as they emerge. This will help to quantify, manage, and utilise their operation in the future.

Actively engaging with aggregators for emergency reserve

The Reliability and Emergency Reserve Trader (RERT) mechanism in the NER allows AEMO, in its role as the system operator, to contract for capacity reserves when a shortfall of reserve is projected.

AEMO is seeking to establish a diverse panel of DER and demand response reserve providers, and is seeking expressions of interest from industry.[78] In the Victorian context, the RERT will help to avoid a reserve shortfall, particularly during peak demand conditions.

Technical review of load models

AEMO has commenced a joint project with several NSPs to revise the dynamic representation of customer load models. These load models are used in both planning and operating the electrical network. High speed measurement data is being collected and used to study the changing dynamics of loads as DER increase.

DER and demand response data gathering

AEMO in its role as the system operator, is collaborating with overseas system operators, and will continue its strategic approach to demand response and DER under the Future Power System Security (FPSS) program[79], as part of our involvement with the GO15[80] initiative and our representation at key CIGRE groups.[81,82]

AEMO is also collaborating with the Energy Market Transformation Project Team (EMTPT), a working group of the Senior Committee of Officials of the Council of Australian Governments (COAG) Energy Council, to explore DER data collection mechanisms.

4.3 Emerging technical challenges and uncertainties

AEMO has identified the following key areas of Victorian power system operation that will be affected by a changing generation mix and demand patterns:

- Frequency control under extreme power system conditions.
- System strength.

4.3.1 Frequency control under extreme power system conditions

Frequency stability is challenged by contingencies that separate networks or otherwise skew the supply-demand balance (that is, disconnection of generation or load).

When a supply-demand imbalance occurs, the frequency will naturally change. Frequency control for credible contingencies are managed through contingency FCAS – allocated generators and loads vary their output or consumption in response to frequency excursions.

[78] AEMO, Reliability and emergency reserve trader (RERT) request for expressions of interest. Available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Emergency-Management/RERT-panel-expressions-of-interest.

[79] AEMO. Future Power System Security Program. Available at: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/FPSSP-Reports-and-Analysis.

[80] The GO15 initiative is a voluntary initiative of the world's 18 largest power grid operators, from six continents, which represent more than 70% of the world's electricity demand and provide electricity to 3.4 billion consumers. More information is available at: http://www.go15.org/.

[81] CIGRE. SC C1 System Development and Economics. Available at: http://www.cigre.org/Technical-activities/Study-Committees-Working-Groups/SC-C1-System-Development-and-Economics.

[82] CIGRE. SC C4 System Technical Performance. Available at: http://www.cigre.org/Technical-activities/Study-Committees-Working-Groups/SC-C4-System-Technical-Performance.

When extreme events cause fast changes in frequency, the automatic disconnection of load or generation may be triggered to prevent a complete system failure. In the most severe conditions, the Rate of Change of Frequency (RoCoF) can be so fast that frequency will drop below a point of no return before automatic schemes can act.

Because Victoria is well interconnected and has a large fleet of synchronous generators, frequency control is unlikely to be a challenge in the coming 10 years. The availability of FCAS is expected to increase as wind generation[83], battery storage, and demand response[84] enter the FCAS markets.

AEMO's studies show that Victorian frequency can be controlled, even for extreme events such as:

- Separation of the Victoria to New South Wales interconnector.
- Loss of a large power station.

Separation of the Victoria to New South Wales interconnector

A separation of the Victoria to New South Wales interconnector would normally require disconnection of at least four transmission lines. Because this series of events is uncommon, the most recent events were almost a decade ago:

- In 2009, a transmission fault resulted in separation after six lines were already out of service due to bushfire-related incidents. The interconnector transfer was about 295 MW towards Victoria when the states finally separated. The minimum frequency observed was 49.71 Hz. In this instance, frequency stability was easily maintained.
- In 2007, both Dederang – South Morang 330 kV transmission lines tripped in quick succession due to a bushfire in the Tatong area in northern Victoria. The power flow on these 330 kV lines automatically transferred to 220 kV lines supplying the Victorian power system from New South Wales, but they could not sustain that loading and tripped in succession. Finally, the increased flow from South Australia through Heywood also could not be sustained, and those 275 kV lines also tripped. About 2,490 MW of customer demand was automatically shed in response to the frequency dip, and this automatic load shedding effectively prevented further frequency collapse.

Schedule 5.2.5.3 of the NER specifies minimum and automatic access standards with respect to the level of RoCoF that new generation over 5 MW must withstand while being capable of continuous uninterrupted operation. Currently, the automatic access standard is that the generator must withstand a RoCoF of 4 Hz per second for a period of 0.25 seconds. The minimum access standard is 1 Hz per second, for a period of one second. In both the 2007 and 2009 events, the measured RoCoF was well below 0.5 Hz/s.

AEMO studied the loss of the Victoria to New South Wales interconnector under a range of increasingly onerous future scenarios. This study mimicked the series of events from 2007, where transmission lines tripped in quick succession to electrically separate Victoria from New South Wales.

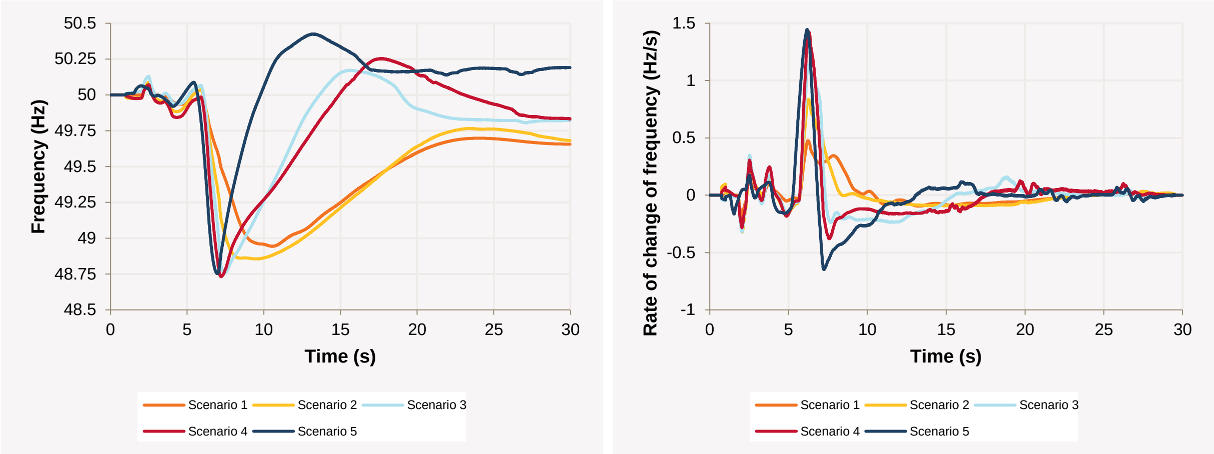
The following figure illustrates the frequency response to this succession of events. In the worst case scenario, RoCoF exceeds 1 Hz/s for about 650 ms, briefly reaching a peak of 1.5 Hz/s.

These studies found that while RoCoF risk for extreme events is increasing over the next 10 years in Victoria, it is unlikely to result in a widespread blackout.

[83] AEMO recommended to the Essential Services Commission of South Australia (ESCOSA) that all new generators greater than 5 MW in South Australia should be required to register for regulation and contingency FCAS. More information is available at: http://www.escosa.sa.gov.au/ArticleDocuments/1048/20170331-Inquiry-RecommendedTechnicalStandardsGeneratorLicensingSA-AEMOadvice.pdf.aspx.

[84] On 24 November 2016, the AEMC amended the NER so that FCAS can be provided by plant not registered in the energy market. The introduction of the Market Ancillary Service Provider (MASP) classification will enable battery storage and DER aggregators to provide FCAS.

Figure 10 Frequency response for a loss of Victoria to New South Wales interconnector*



* Scenarios 1 to 5 reflect varying levels of online synchronous generating units contributing to frequency recovery.

Loss of a large power station

While all interconnectors are in service, frequency is controlled on the mainland using services in any region. For this reason, contingencies outside Victoria can pose a risk to frequency stability within Victoria.

The 2016 NTNDP studied mainland frequency control for the loss of the largest power station. This is defined as non-credible in the NER (since it involves simultaneous loss of multiple generating units), and is considered to be a very extreme event. In reality, power station failures tend to disconnect generating units several seconds or tens of seconds apart, resulting in a much slower RoCoF.

The study found that, even for this extreme contingency event, mainland RoCoF would have remained below 1 Hz/s in recent years. Some increase is projected in future, with RoCoF slightly exceeding 1 Hz/s almost 5% of the time by 2026–27. At this level of RoCoF, the power system is likely to remain stable, although UFLS may temporarily disconnect a small portion of consumer load. See Section 4.2.1 of the 2016 NTNDP[85] for more information on the system-wide risks of high RoCoF.

4.3.2 System strength

As noted in Section 4.2.1, system strength is degrading due to the electrical distance (network impedance) between local terminal stations in western Victoria and connected synchronous plant.

AEMO has performed a high-level assessment to locate areas where system strength is an existing or emerging challenge. An area of the grid is generally considered weak if the Short Circuit Ratio (SCR)[86] drops below three.[87] For this assessment, the weighted[88] SCR was calculated for possible connections to determine network strength.

The results of this assessment are illustrated in Figure 11 below, which highlights that network strength is projected to decline further in much of north-west Victoria.

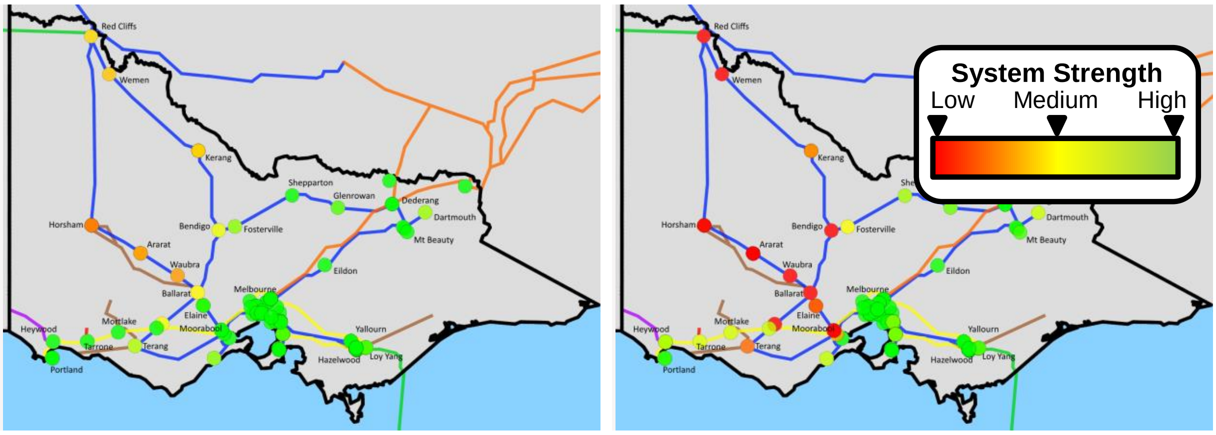
[85] AEMO. 2016 NTNDP. Available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Transmission-Network-Development-Plan.

[86] SCR is the ratio of the power system fault level at a connection point to the rated local generation.

[87] Y Zhang, S Huang, J Schmall, J Conto, J Billo, E Rehman, "Evaluating System Strength for Large-Scale Wind Plant Integration", PES General Meeting | Conference & Exposition, 2014 IEEE.

[88] Weighted SCR takes into account the interaction between inverter-connected generation on the short circuit ratio.

Figure 11 System strength in 2017–18 (left) and 2026–27 (right)

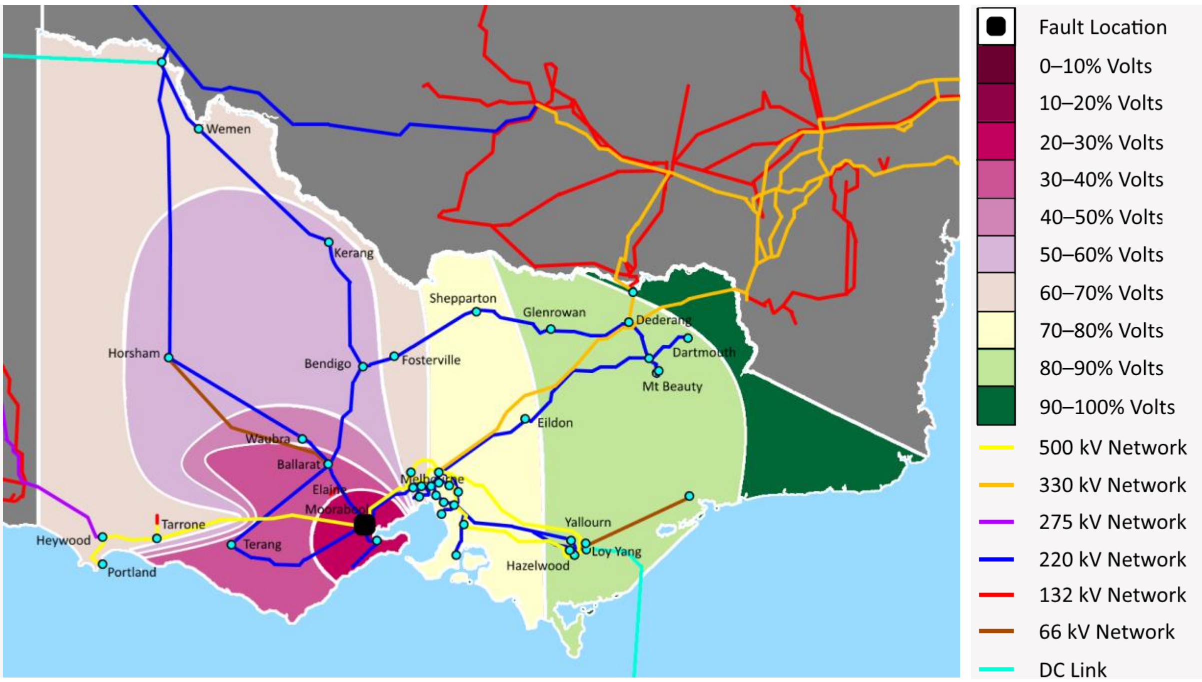


The effects of low system strength on system disturbances are deeper voltage dips, slower voltage recovery, and reduced power quality. The geographic spread and the depth of voltage dips increase as system strength decreases.

A voltage dip (also called a voltage sag) is a brief drop in network voltage following a fault or switching event. It can have varied impacts on the operation of motors and sensitive electronics, such as computers, depending on its magnitude and duration. In a weak network area, voltage dips are deeper, more widespread, and can last longer than in a strong network.

Figure 12 below shows the depth and spread of a voltage dip resulting from a fault at Moorabool. In this example, the voltage dip is observed below 80% of nominal voltages on the transmission network in central and western Victoria. For wind farms, when the turbine voltage drops below the fault ride-through threshold (normally 80 to 90% of its nominal voltage), the turbine suspends normal operation and starts injecting reactive current. Most existing wind turbines are designed to withstand zero voltage at their terminals for 150 milliseconds or longer.

Figure 12 Voltage dip propagation for a three phase fault at Moorabool



During a network fault, these generators tend to reduce their active power generation and supply reactive power. Following fault clearance, the generating systems are designed to immediately resume active power generation (depending on the capability of the generator and the kind of fault). This capability is important to ensure generation is available after the network fault is cleared. Voltage control requirements are specified within the generator performance standards for all new connections (See S5.2.5.1 for requirements on reactive power capability in the NER[89]).

In a weak system, where the impact of the network fault is widespread, a large amount of generation can enter fault ride-through during the brief period before a fault is isolated, resulting in a power imbalance. This imbalance can result in:

- Voltage Dip Induced Frequency Dip (VDIFD) – where the power imbalance affects frequency.
- Voltage Dip Induced Power Shift (VDIPS) – where the power imbalance affects inter-area power transfer.

Voltage Dip Induced Frequency Dip (VDIFD)

When multiple inverter-connected generators simultaneously halt active power production, power system frequency will dip. AEMO studied VDIFDs for Victoria, and found that the challenges are currently managed effectively through the existing FCAS. Through the 10-year outlook, Victoria's strong interconnection and large fleet of synchronous generation is expected to adequately support frequency during VDIFDs.

Voltage Dip Induced Power Shift (VDIPS)

When multiple nearby inverter-connected generators simultaneously halt active power production, their generation deficit will be partially displaced by synchronous generation, resulting in a swing in power transfers. These power transfers have the potential to trigger protection systems, resulting in automatic load disconnection.

AEMO found that VDIPSs in north-west Victoria will be less severe than traditional transmission contingencies, and are unlikely to trigger protection systems due to the number of electrical pathways out of the area. Control schemes that monitor current flow may incorrectly operate, or operate slower than designed, in response to large and sustained power swings.

AEMO will continue to review the impact of VDIPSs in Victoria, particularly as they relate to the correct operation of protection and control systems, as inverter-connected generators connect in close proximity.

In addition to voltage dip propagation, low system strength in western Victoria can also degrade elements of system performance, or threaten power system security, due to other factors such as:

- Inability to control voltage during normal system and market operations, such as switching of transmission lines or transformers, switching reactive plant (capacitors and reactors), transformer tap changing, and routine variations in load or generation. Synchronous plant may also suffer instability if connected to a weak network.
- Manufacturers' design limits on power electronic converter-interfaced devices such as wind turbines, solar PV systems, and static VAr compensators. Operation of these devices outside their minimum design limits could give rise to generating system instability and consequent disconnection from the grid.
- Protection systems that rely on measurement of current (excluding differential protection), or current and voltage during a network fault to achieve two basic design requirements:
  - Selectivity (that is, to operate only for conditions for which the system has been installed).

[89] AEMC, National Electricity Rules, version 83. Available at: http://www.aemc.gov.au/getattachment/eba46bef-815b-4d84-a581-bbb1356c4822/National-Electricity-Rules-Version-83.aspx

– Sensitivity (that is, to be sufficiently sensitive to faults on the equipment it is protecting).

AEMO is investigating the impacts of low system strength in western Victoria under the Western Victoria Renewable Integration RIT-T.[90]

Improving system strength

System strength cannot be imported, and must be supplied locally. Solutions to improve system strength include:

- Synchronous condensers.
- Synchronous machines (synchronous generators).
- Static synchronous compensators (STATCOMs), or other voltage source converter (VSC) technology, with energy storage or transfer.

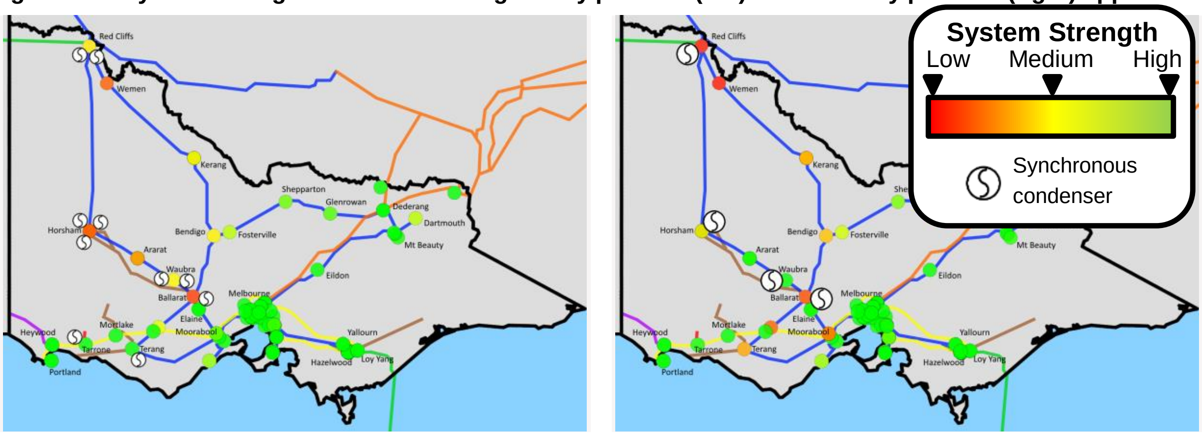
In the absence of improving system strength, renewable generator capabilities and protection design may need to be updated to accommodate further decreases in system strength in some areas of the network.

The NER are unclear on who has responsibility for system strength, but the AEMC is considering changes to the NER that will impose such responsibility on NSPs as part of its SSMF Review.[91] AEMO has made a submission to this review.[92] Network investments to improve system strength will allow connection of more non-synchronous generation in western Victoria.

Figure 13 shows the placement of synchronous condensers to supply system strength under two planning scenarios:

- A local approach, where individual generator projects are required to supply system strength.
- A centralised approach, where system strength is strategically coordinated.

Figure 13 System strength in 2026–27 using locally planned (left) and centrally planned (right) approach



In the locally planned approach, a greater number of smaller synchronous condensers are needed compared to the centrally planned approach. While the centrally planned approach achieves a lower overall cost (saving approximately $60 to $100 million in this instance), it assumes good foresight of generator connections. The benefit of the locally planned approach is that it removes the risk of stranded assets should generators not connect. AEMO is assessing options to improve system strength in western Victoria under the Western Victoria Renewable Integration RIT-T.[93]

[90] AEMO. Regulatory Investment Tests for Transmission. 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.
[91] Available at: http://www.aemc.gov.au/Markets-Reviews-Advice/System-Security-Market-Frameworks-Review.
[92] Available at: http://www.aemc.gov.au/getattachment/94177d01-4833-413e-b012-99ba52113452/AEMO.aspx.
[93] AEMO. Regulatory Investment Tests for Transmission. 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.

Impact on control schemes

Increasing amounts of renewable generation and low system strength will affect the efficacy of control schemes. AEMO has reviewed Victorian control schemes with respect to their performance as renewable penetration increases in western Victoria. This review found that:

- New generator and network augmentations will impact existing control schemes in western Victoria. These control schemes will be reviewed as projects progress through the connection process.
- Control schemes that manage voltages at Tarrone and Mortlake 500 kV terminal stations will be reviewed as additional reactive power support is introduced by generators connecting in the area.
- Usage of the System Overload Control Scheme (SOCS) in western Victoria may reduce as new generation connects to the network, depending on the precise location of connections.
- Generators connecting in western Victoria may be required to participate in fast operating control schemes (such as runback or generator shedding).

Table 7 Summary of existing control schemes that may be impacted by new generation connecting in western Victoria

Control scheme	Primary function	Normally enabled	Location of monitored elements	Action
Ballarat–Horsham 66 kV Tie Split Scheme	Thermal limitations	Yes	Western Victoria	Network reconfiguration
Murraylink Automatic Slow and Very Fast Runback Schemes	Thermal limitations & instability	Yes	Western Victoria and Shepparton area	Murraylink interconnector runback
Ararat Wind Farm Fast Trip Scheme	Thermal limitations & instability	Yes	Western Victoria	Generation shedding
Waubra Wind Farm Trip Scheme	Anti-Islanding Thermal limitations	Yes	Western Victoria	Generation shedding
Mt Mercer Wind Farm Runback Scheme	Thermal limitations	No	Western Victoria	Generation runback
Tarrone Overvoltage Protection Scheme	Overvoltage	Yes	Western Victoria	Network switching
Mortlake Overvoltage Protection Scheme	Overvoltage	Yes	Western Victoria	Network switching
Emergency Moorabool Transformer/Reactor Trip	Thermal limitations & reverse power flow	Yes	Western Victoria	Network switching
SOCS on Ballarat–Bendigo 220 kV line	Thermal limitations	No	Western Victoria	Load shedding and generation runback
SOCS on Ballarat–Moorabool No.1 220 kV line	Thermal limitations	No	Western Victoria	Load shedding
Interconnector Emergency Control Scheme (IECS)	Power system stability	No	Northern Corridor and Greater Melbourne	Load shedding and Murraylink interconnector runback
Automatic Under Frequency Load Shedding Scheme	Power system frequency	Yes	Victorian terminal stations, aluminium smelter potlines and specific zone substations	Load shedding

APPENDIX A. DSN MONITORED LIMITATION DETAIL

These details for monitored transmission network limitations are grouped geographically.

A number of limitations previously identified as monitored are no longer included in the 2017 VAPR. Because their triggers are now unlikely to occur, they have been reclassified as an emerging development opportunity (see Section 3.5), or have been incorporated into the Western Victoria Renewable Integration RIT-T. This is due to changes in network loading resulting from committed network projects, projected decreases in demand, or change in generation mix.

The options presented in the sub-sections below should be treated as indicative only and a RIT-T will be required to determine the full list of network and non-network options as well as the preferred option. The preferred option may include one or a combination of the options presented in the sub-sections below.

A.1 Eastern Corridor – monitored limitations

Table 8 Limitations being monitored in the Eastern Corridor

Limitation	Possible network solution	Trigger*	2016 NTNDP status	Contestable project status
Rowville – Yallourn 220 kV line loading	Upgrade the 220 kV Hazelwood–Rowville or Yallourn–Rowville lines.	During period of extremely high temperature and high output from Yallourn power station.	The NTNDP did not identify this as a material limitation in the scenarios modelled.	The line upgrade is unlikely to be a contestable project.

* Triggers are the operating conditions under which a limitation may result in supply interruptions or constrain generation periodically.

A.2 South-West Corridor – monitored limitations

Table 9 Limitations being monitored in the South-West Corridor

Limitation	Possible network solution	Trigger*	2016 NTNDP status	Contestable project status
Moorabool – Heywood – Portland 500 kV line voltage unbalance**	A switched capacitor with individual phase switching at Heywood or near Alcoa Portland with an estimated cost of $13.9 million. A static VAr compensator (SVC) or a synchronous static compensator (STATCOM) at an estimated cost of $32.3 million. Additional transposition towers along the Moorabool – Heywood – Alcoa Portland 500 kV line at an estimated cost of $36.7 million.	New generation connections along the Moorabool–Heywood–Alcoa Portland 500 kV line potentially introduce voltage unbalance along the line. The impact of voltage unbalance levels increase in proportion to power flow magnitude and direction, new generation connection points, and output generated.	This limitation was not considered as part of 2016 NTNDP scope as it is related to voltage quality.	The switched capacitor and static VAr options are likely to be contestable projects. The line transposition is unlikely to be a contestable project.
Inadequate South-west Melbourne 500 kV thermal capacity	A new Moorabool – Mortlake/Tarrone –Heywood 500 kV line with an estimated cost of $541.7 million.	If significant wind generation and/or gas-powered generation (GPG) (over 2,500 MW in addition to the existing generation from Mortlake) is connected to the transmission network in the South-West Corridor.	The NTNDP did not identify this as a material limitation in the scenarios modelled.	The new line is likely to be a contestable project.

* Triggers are the operating conditions under which a limitation may result in supply interruptions or constrain generation periodically.
** AEMO intends seeking a rule change proposing an increase the negative sequence voltage imbalance levels on the transmission network.

A.3 Northern Corridor – monitored limitations

Table 10 Limitations being monitored in the Northern Corridor

Limitation	Possible network solution	Trigger*	2016 NTNDP status	Contestable project status
Murray – Dederang 330 kV line loading	Install a third 1,060 MVA 330 kV line between Murray and Dederang with an estimated cost of $180.3 million (excluding easement costs). Install a second 330 kV line from Dederang to Jindera at an estimated cost of $149 million (excluding easement costs).	Increased NSW import and Murray generation.	The NTNDP did not identify this as a material limitation in the scenarios modelled.	These are both likely to be contestable projects.
Dederang – South Morang 330 kV line loading	Up-rate the two existing lines to 82 ºC (conductor temperature) operation and series compensation at an estimated cost of $16.5 million. Install a third 330 kV, 1,060 MVA single circuit line between Dederang and South Morang with 50% series compensation to match the existing lines, at an estimated cost of $239.6 million (excluding easement costs, and subject to obtaining the necessary easement).	Increased NSW import. This constraint will be alleviated by the development proposed to increase the VIC to NSW export limit.	This constraint was identified in the NTNDP during high transfer between VIC to NSW (export or import)	The new line is likely to be a contestable project.
Dederang – Mount Beauty 220 kV line loading	Install a wind monitoring scheme with an estimated cost of $535.4k. Up-rate the conductor temperature of both 220 kV circuits between Dederang and Mount Beauty to 82 ºC, at an estimated cost of $12.2 million.	Increased NSW import and export.	This constraint was identified in the NTNDP during high export to NSW	These are unlikely to be contestable projects.
Eildon – Thomastown 220 kV line loading	Install wind monitoring scheme at an estimated cost of $535.4k. Up-rate the Eildon – Thomastown 220 kV line, including terminations to 75 ºC operation, at an estimated cost of $43.7 million.	Increased NSW import and export.	This constraint was identified in the NTNDP during high import from NSW	This is unlikely to be a contestable project.
Dederang 330/220 kV transformer loading	Install a fourth 330/220 kV transformer at Dederang at an estimated cost of $21.2 million.	At times of over 2,500 MW of imports from NSW and Murray generation (with the DBUSS transformer control scheme being active).	The NTNDP did not identify this as a material limitation in the scenarios modelled.	The new transformer is likely to be a contestable project.

* Triggers are the operating conditions under which a limitation may result in supply interruptions or constrain generation periodically.

A.4 Greater Melbourne and Geelong – monitored limitations

Table 11 Limitations being monitored in the Greater Melbourne and Geelong

Limitation	Possible network solution	Trigger*	2016 NTNDP status	Contestable project status
Rowville – Malvern 220 kV line loading**	Cut-in the Rowville – Richmond 220 kV No.1 and No.4 circuits at Malvern Terminal Station to form the Rowville – Malvern – Richmond No.3 and No.4 circuits at an estimated cost of $10.8 million.	Increased demand or additional loads connected to Malvern Terminal Station.	NTNDP did not identify this limitation as it is a localised issue.	The line cut-in is unlikely to be a contestable project.
Rowville – Springvale – Heatherton 220 kV line loading	Connect a third Rowville – Springvale circuit (underground cable) with an estimated cost of $54.1 million. Connect a Cranbourne – Heatherton 220 kV double circuit overhead line with an estimated cost of $35 million.	Increased demand or additional loads connected to Springvale and Heatherton Terminal Station.	NTNDP did not identify this limitation as it is a localised issue.	The third circuit is likely to be a contestable project.
Rowville A1 500/220 kV transformer loading	Install a second 500/220 kV 1,000 MVA transformer at Cranbourne with an estimated cost of $40.6 million.	Increased demand in Eastern Metropolitan Melbourne.	The NTNDP did not identify this as a material limitation in the scenarios modelled.	The new transformer is likely to be a contestable project.
South Morang H1 330/220 kV transformer loading	Replace the existing transformer with a higher rated unit in conjunction with SP AusNet's asset replacement program.	Increased demand in Metropolitan Melbourne and/or increased import from NSW.	The NTNDP did not identify this as a material limitation in the scenarios modelled.	This is unlikely to be a contestable project.
South Morang – Thomastown No.1 and No.2 220 kV line loading	Install an automatic load shedding control scheme to enable the use of five minute line rating. Install a third 500/220 kV transformer at Rowville, with an estimated cost of $40.6 million, plus any fault level mitigation works.	Increased demand around the Melbourne Metropolitan area and/or increased export to NSW.	NTNDP did not identify this limitation as it is a localised issue.	The new transformer is likely to be a contestable project.
Cranbourne A1 500/ 220 kV transformer loading	Install a new 500/220 kV transformer at Cranbourne Terminal Station with an estimated cost of $39.6 million (excluding easement cost).	Increased demand around the Eastern Melbourne Metropolitan area.	The NTNDP did not identify this as a material limitation in the scenarios modelled.	The new transformer is likely to be a contestable project.
Moorabool – Geelong - Keilor 220kV line loading	Connect a new single circuit Moorabool – Geelong 220kV line with a rating of approximately 800MVA at 35ºC, with an estimated cost of $11 million. Replace the existing Geelong – Keilor 1 and 3 220kV lines with a new double circuit line, each circuit rated at 700MVA at 35ºC, with an estimated cost of $74 million.	Large scale new generation connected to western Victoria area, and congestions within Western Vic are relieved to allow the new generation to be sent out of the western Victoria areas.	This constraint was identified in the NTNDP during high renewable generation, if large amount of wind and solar generation is connected to the north-west Victoria.	This is unlikely to be a contestable project.
Keilor – Deer Park – Geelong 220 kV line loading***	Connect a second 220kV line (Keilor – Geelong No.1) at Deer Park at an estimated cost of $12.3 million.	Increased demand at Deer Park	NTNDP did not identify this limitation as it is a localised issue.	These are unlikely to be contestable projects.

* Triggers are the operating conditions under which a limitation may result in supply interruptions or constrain generation periodically.
** This monitored limitation assumes five minute ratings are already applied – an automatic load shedding control scheme to enable the use of five minute line ratings is currently available to manage this limitation.
*** This monitored limitation assumes five minute ratings will be applied – an automatic load shedding control scheme to enable the use of five minute line ratings will be available to manage this limitation.

A.5 Regional Victoria – monitored limitations

Table 12 Limitations being monitored in Regional Victoria*

Limitation	Possible network solution	Trigger**	2016 NTNDP status	Contestable project status
Inadequate reactive power support in Regional Victoria	Staged installation of additional reactive power support in Regional Victoria.	Increased demand and/or decrease in power factor in Regional Victoria.	NTNDP did not identify this limitation as it is a localised issue.	Additional reactive support is unlikely to be a contestable project.
Dederang – Glenrowan Shepparton – Bendigo 220 kV line loading	Install an automatic load shedding control scheme to enable the use of five minute line rating. Install a phase angle regulating transformer on the Bendigo – Fosterville – Shepparton 220 kV line at an estimated cost of $46 million. Replace the existing Dederang – Glenrowan, Glenrowan – Shepparton and Shepparton – Bendigo 220 kV lines with new double circuit lines at respective estimated costs of $68 million, $61 million, and $94 million (a total of $223 million).	Increased demand in Regional Victoria and/or increased import from NSW.	NTNDP did not identify this limitation as it is a localised issue.	The new transformer or new transmission lines are likely to be contestable projects.

* AEMO is conducting a RIT-T to identify the preferred augmentation option to address DSN capacity limitations in the regional Victoria. The outcome of this RIT-T will affect the status of the limitations in this area.
** Triggers are the operating conditions under which a limitation may result in supply interruptions or constrain generation periodically.

APPENDIX B. DISTRIBUTION NETWORK SERVICE PROVIDER PLANNING

This appendix lists the preferred connection modifications from the *2016 Transmission Connection Planning Report*[94] and the potential DSN impacts and considerations.

Table 13 Distribution network service provider planning impacts

Location/terminal station	Preferred connection modification	DSN impacts and considerations
Brunswick 66 kV	Establish a new 66 kV supply point with three 225 MVA 220/66 kV transformers in late 2016. This enables West Melbourne and Richmond Terminal Station off-loading (in late 2016 and by summer 2019–20 respectively) and increases local supply reliability.	The transfer of load from the west and east of the Melbourne Metropolitan Area to its north has been taken into consideration in AEMO's assessment of upcoming constraints.
Cranbourne 66 kV	Install a fourth Cranbourne 150 MVA 220/66 kV transformer by end of 2024.	Increased demand requiring this transformer will be included in Greater Melbourne and Geelong planning.
Deer Park 66 kV	Establish a terminal station at Deer Park with two 225 MVA 220/66 kV transformation supplied from Keilor – Geelong 220 kV transmission by November 2017.	Offloading from Altona Terminal Station West and Altona Terminal Station/Brooklyn Terminal Station will defer the augmentation from those stations. Load transfer to Deer Park Terminal Station will increase line flows in the Western Melbourne Metropolitan Area transmission loop and has been taken into consideration in AEMO's assessment of upcoming constraints.
Frankston 66 kV	Implement dynamic line ratings on the Cranbourne – Frankston 66 kV lines by 2017–18 and centralised automatic load shedding scheme (SOCS) for the two lines at Cranbourne by summer 2023.	Impact of the dynamic line ratings and load shedding scheme on the transmission network will be assessed closer to the proposed installation date.
Red Cliffs 66kV	A distribution reinforcement project to re-conductor part of the Wemen – Robinvale 66 kV line is planned to be completed in 2018. This allows a temporary distribution load transfer from Red Cliffs to Wemen, deferring need for additional Red Cliffs transformation.	This re-conductoring and temporary load transfer won't significantly impact the transmission network.
Richmond 66 kV	Permanently transfer load from Richmond Terminal Station 66 kV to new Brunswick Terminal Station 66 kV, which will be done via sub transmission networks by summer 2019–20. Prior to establishing the Brunswick 66 kV switchyard, emergency load transfers from Richmond 1&2 bus group to the Malvern Terminal Station will be available. Subject to availability, installation of AusNet Transmission Group's spare 220/66 kV transformer for metropolitan areas could be undertaken to temporarily replace a failed transformer at Richmond Terminal Station 66 kV.	The impact of the load transfer has been taken into consideration in AEMO's assessment of upcoming constraints. The contingency plan for emergency load transfer and temporary Richmond Terminal Station transformer/s will help to reduce the load at risk.
South Morang 66 kV	Install a third 225 MVA 220/66 kV transformer and three fault limiting series reactors by 2024–25.	Increased demand requiring this transformer will be included in Regional Victoria planning.

[94] Jemena, CitiPower, Powercor, AusNet Services and United Energy. *2016 Transmission Connection Planning Report.* Available at: https://www.unitedenergy.com.au/wp-content/uploads/2016/12/Transmission-Connection-Planning-Report-TCPR-2016.pdf.

Location/terminal station	Preferred connection modification	DSN impacts and considerations
Springvale 66kV	Replace three of the four Springvale Terminal Station 'B' transformers in 2021, as part of AusNet Transmission Group's asset replacement program. Rebalance the bus group loads by transferring Oakleigh East and Clarinda zone sub from SVTS 12 to 34 66kV bus group coincident with asset renewal project, if economic; otherwise not before 2025. Transfer load off Springvale to the proposed Dandenong Terminal Station shortly after 2025.	Need to extend existing easements to supply Dandenong Terminal Station that United Energy considers may be viable shortly after 2025.
Terang 66 kV	Install a third 150 MVA 220/66 kV transformer, not before 2022, if non-network support unavailable.	Increased demand requiring this transformer will be included in Regional Victoria planning.
West Melbourne 66 kV	Transfer load to the proposed Brunswick 66 kV connection point in late 2016.	The impact of the load transfer has been taken into consideration in AEMO's assessment of upcoming constraints.
West Melbourne 22 kV	Transfer load to adjacent stations and retire all of the existing WMTS 22 kV systems by the end of 2023.	The impact of the load transfer has been taken into consideration in AEMO's assessment of upcoming constraints.

APPENDIX C. TRANSMISSION NETWORK LIMITATION REIVEW APPROACH

In assessing the impact of limitations, AEMO considers information from power system performance analysis and market simulations each year for the next ten years regarding:

- The percentage N and N–1 loadings of transmission plant associated with the network loading limitation, based on the continuous and short-term ratings respectively.
- The load and energy at risk. Load at risk is the load shedding required to avoid the network limitation. Energy at risk is the resulting unserved energy (USE).
- Expected USE, which is a portion of the energy at risk after taking into account the probability of forced outage.
- Dispatch cost, which is the additional cost from constraining generation.
- Limitation cost, which is the total additional cost due to both constraining generators and the expected USE.

Power system performance analysis generally uses more conservative assumptions about demand, temperature, and wind speed to capture as many network limitations as possible for later market simulation testing. For this reason, DSN performance analysis results (that is, the percentage loadings) can show more severe impacts than the market simulations.

AEMO derives forecast transmission plant loadings using load flow simulations, and develops load flow base cases for these simulations using the following inputs:

- The 10% probability of exceedance (POE) terminal station demand for maximum demand base cases. For more information, see *2016 Transmission Connection Point Forecasting Report for Victori*a (see Section 1.1).
- Historical maximum power transfers for a high Victoria to New South Wales power transfer base case.
- Typical generation dispatch and interconnector power transfer patterns under the given operating conditions.
- The system normal operational configuration for the existing Victorian transmission network.
- Committed transmission network augmentation and generation projects, and other projects (or their equivalent), which AEMO considers necessary for maintaining the power system in a satisfactory, secure, and reliable state during summer maximum demand periods.
- Standard continuous ratings and short-term ratings at 45 ºC and 0.6 m/s wind speed, unless otherwise indicated.[95]
- Unless indicated, 15-minute ratings are used as short-term ratings for transmission lines. Some transmission lines in Victoria are equipped with automatic load shedding schemes, which, once enabled, will avoid overloading by disconnecting preselected load blocks following a contingency. These schemes allow the lines to operate up to their five minute short-term ratings.
- Wind generation availability during maximum demand of 6.5% of the installed capacity is assumed. For more information, see the Wind Contribution to Peak Demand study results.[96]

[95] For lines with wind monitoring installed, historical wind speed data was analysed to identify the wind speed occurring during the top 5% of demand periods with a 95% confidence interval.

[96] AEMO. *Wind Contribution to Peak Demand*, 2012. Available at http://www.aemo.com.au/Electricity/Planning/Related-Information/Wind-Contribution-to--Peak-Demand.

AEMO bases the market impact of each network limitation on probabilistic market simulations that apply the following:

- Weighted 50% POE and 10% POE maximum demand forecasts (weighted 70% and 30% respectively).
- Historical wind generation availability.
- Historical load profiles.
- Dynamic ratings based on historical temperature traces.
- Non-committed new and retired generation, consistent with latest NTNDP generation expansion plan.

For more information about the transmission network limitation review approach, see the *Victorian Electricity Planning Approach*.[97]

[97] AEMO. *Victorian Electricity Planning Approach*, 2016. Available at http://www.aemo.com.au/Electricity/Policies-and-Procedures/Planning/Victorian-Electricity-Planning-Approach.

MEASURES AND ABBREVIATIONS

Abbreviation	Full term
AEMO	Australian Energy Market Operator
DSN	Declared Shared Network
MW	Megawatts
NEFR	National Electricity Forecasting Report
NEM	National Electricity Market
NEMDE	National Electricity Market Dispatch Engine
NSCAS	Network Support and Control Ancillary Service
NTNDP	National Transmission and Development Plan
RIT-T	Regulatory Investment Test for Transmission
USE	Unserved energy
VAPR	Victorian Annual Planning Report

GLOSSARY

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

Glossary term	Definition
active power	Active 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).
annual planning report	An annual report providing forecasts of gas or electricity (or both) supply, network capacity and demand, and other planning information.
black system	The absence of voltage on all or a significant part of the transmission system or within a region during a major supply disruption affecting a significant number of customers.
committed projects	Generation that is considered to be proceeding under AEMO's commitment criteria.
constraint	A limitation on the capability of a network, load, or generating unit such that it is unacceptable to either transfer, consume, or generate the level of electrical power that would occur if the limitation was removed.
contestable augmentation	An electricity transmission network augmentation for which the capital cost is reasonably expected to exceed $10 million and that can be constructed as a separate augmentation (that is, the assets forming that augmentation are distinct and definable).
electrical energy	Average electrical power over a time period, multiplied by the length of the time period.
limitation (electricity)	Any limitations on the operation of the transmission system that could give rise to unserved energy or to generation re-dispatch costs.
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 Market	The wholesale market for electricity supply in Queensland, New South Wales, the Australian Capital Territory, Victoria, Tasmania, and South Australia.
reactive power	Reactive power, which is different to active power, is a necessary component of alternating current electricity. It is predominantly consumed in the creation of magnetic fields in motors and transformers. Management of reactive power is necessary to ensure network voltage levels remain within required limits, which is in turn essential for maintaining power system security and reliability.
unserved energy	The amount of energy that cannot be supplied because there is insufficient generation or network capacity to meet demand.