Victorian reactive power support

May 2018

Regulatory Investment Test For Transmission
Project Specification Consultation Report

Important notice

PURPOSE

AEMO has prepared this document to provide information about potential network limitations in Victoria and potential options to address these limitations, as at the date of publication, in accordance with clause 5.16.4 of the National Electricity Rules.

DISCLAIMER

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Executive summary

The Regulatory Investment Test for Transmission (RIT-T) is an economic cost-benefit test used to assess and rank different electricity transmission investment options that address an identified need. Its purpose is to identify the investment option which maximises the present value of net economic market benefit to all those who produce, consume and transport electricity in the market.

AEMO's 2017 *Victorian Annual Planning Report* (VAPR) identified an increasing need for additional reactive support to maintain transmission system voltages within operational limits during minimum demand periods. Further study following the 2017 VAPR has confirmed that there is currently an identified need for investment in options which can suppress high voltages in the Victorian transmission network. This need is driven by recent changes in the Victorian transmission power system, as well predicted changes in the planning time frame, including:

- Hazelwood Power Station closed in March 2017, removing 1,600 megawatts (MW) of brown coal generation capacity, together with its reactive power capability to regulate voltage.
- The reduction in operational demand during light load conditions and the predicted shifting of minimum operational demand to middle of the day. The occurrence of these two phenomena is predicted to accelerate in the near future mainly due to continued growth in rooftop solar photovoltaic (PV) installations.
- Expected increased penetration of large-scale renewable generation and withdrawal of thermal plant will see non-synchronous generation replace synchronous plant. If not managed this transition will result in a reduction in overall reactive power availability in the transmission network due to the generally lower reactive capability of non-synchronous generation.

AEMO is undertaking this RIT-T to assess network and non-network options that are considered technically and economically feasible to meet the identified need. From the feasible options the RIT-T process will identify the preferred option and its optimal timing.

This Project Specification Consultation Report (PSCR) is the first stage of the RIT-T process and includes:

1. A description of the identified need.
2. A description of the network options being considered to meet the identified need.
3. The technical characteristics and performance requirements that a non-network option would need to meet the identified need.
4. Specific categories of market benefit and their applicability to this RIT-T.

Next steps

The second stage of the RIT-T process – full options analysis and publication of the Project Assessment Draft Report (PADR) – will be published in accordance with the requirements of clause 5.16.4 of the National Electricity Rules (NER).

Submissions

AEMO welcomes written submissions on this 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 7 August 2018.

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.

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1. Introduction

This Project Specification Consultation Report (PSCR) has been prepared in accordance with the requirements of clause 5.16 of the National Electricity Rules (NER), for a Regulatory Investment Test for Transmission (RIT-T).

In line with these requirements, this PSCR describes:

1. The identified need that AEMO is seeking to address and the assumptions used in identifying the need.
2. The technical characteristics that a non-network option would be required to deliver to meet the identified need.
3. All credible options that AEMO is aware of that can meet the identified need.
4. The classes of market benefit that are unlikely to be material.

The next stage of the RIT-T process is a full option analysis and publication of the Project Assessment Draft Report (PADR), in accordance with the requirements of clause 5.16.4 of NER.

The PADR will include information on the preferred option which returns the higher net market benefit, details on its technical characteristics, estimated implementation date, and analysis showing that the preferred option satisfies the RIT-T.

2. Identified need

2.1 Background

The power system has been undergoing a transformational change, with an unprecedented increase in distributed energy resources (DER) such as rooftop photovoltaic (PV). This transformation, is driving a change in the daily demand profile, shifting the time of minimum demand from early morning (3.00 am to 4.00 am) towards the middle of the day when the solar irradiation is highest. This is, in turn, resulting in a trend of reducing minimum demand.

AEMO's 2017 *Victorian Annual Planning Report* (VAPR) identified a need for additional reactive support to maintain transmission system voltages within operational limits during minimum demand periods. Further study following the 2017 VAPR has confirmed that there is currently an identified need for investment in options which can suppress high voltages in the Victorian transmission network. This need is expected to increase over the next 10 years, mainly due to forecast reduction in minimum demand.

This need is driven by recent changes to the network operating conditions, as well expected changes in the planning timeframe, including:

- The closure of Hazelwood Power Station in March 2017, which removed 1,600 megawatts (MW) of brown coal generation capacity, together with its reactive power capability to regulate voltage.
- The reduction in operational demand during light load conditions and the predicted shifting of minimum operational demand time to middle of the day. The occurrence of these two phenomena is predicted to accelerate in the near future, mainly due to continued growth in rooftop solar PV installations.
- The expected increase in penetration of large-scale renewable generation and withdrawal of thermal power generating units will need non-synchronous generation replacing synchronous generation. If not managed, this transition will result in a reduction in overall reactive power capability in the transmission network due to the generally lower reactive capability of non-synchronous generation.
- Retirement of reactive power plant in Victoria, which was used for voltage support and control.
- Closure of Point Henry Smelter.

AEMO forecasts that the minimum operational demand (on a sent out basis)[1] for Victoria in summer will be reduced from approximately 2,300 MW in 2016-17 to 1,700 MW in 2021-22, and 900 MW in 2026-27. These forecasts include projections of increasing uptake of batteries and electric vehicles (EVs). Batteries and EVs may slow this trend as more are charged in the middle of the day from rooftop PV.

If unmanaged, the lower minimum demands will lead to high voltages and potentially even high voltage violations (that is, voltages exceed defined operating limits). High voltage violations are undesirable, because there is a risk of damage to power system plant if no measure is taken to suppress them. AEMO is managing these high voltages by short-term operational measures and assessing long-term solutions to address this problem.

AEMO is undertaking this RIT-T to assess network and non-network options which are considered as technically and economically feasible to meet the identified need. From the feasible options, the RIT-T will identify the preferred option and its optimal timing of implementation.

2.2 Description of the identified need

AEMO has identified a need for additional reactive support, to:

- Maintain voltages within operational and design limits during minimum demand periods, and to maintain the power system in a satisfactory and secure operating state[2].

[1] AEMO minimum demand forecast and operational demand definition can be found on AEMO's website at http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Electricity-Forecasting-Insights/2017-Electricity-Forecasting-Insights/Summary-Forecasts.

[2] Refer to Chapter 4 of the NER for definitions of a satisfactory or secure operating state.

- Reduce reliability risk from the de-energisation of 500 kilovolt (kV) lines.
- Reduce market impact from the de-energisation of 500 kV lines.

Observations and assessments

Lightly loaded Transmission lines produce reactive power. The higher the transmission line operating voltage, and the longer the line, the higher the amount of reactive power that could be discharged into the power system. Excessive generation of reactive power can create unacceptable over-voltages. Therefore, de-energisation of high voltage and long transmission lines has been used as a short-term operational measure, to manage high transmission system voltages. This would typically be when all standard practices, such as utilising reactive plant, the reactive power capabilities of generating units, and transformer tapping, are exhausted.

High voltages on the 220 kV and 500 kV network in the South-West Corridor around Geelong, Keilor, Portland, and Moorabool have been observed during minimum demand periods and are expected to worsen with projected reductions in minimum operational demand. Before March 2017 AEMO managed excessively high voltages with short-term de-energisation of a single 500 kV line when other means of voltage control had been exhausted.

Following the closure of Hazelwood in March 2017 the frequency of low 500 kV line loading under minimum demand conditions has increased, and AEMO and Victorian Distribution Network Services Providers (DNSPs) have jointly investigated the option of switching off distribution capacitors during light load periods to manage high voltages. This measure can compensate the loss of reactive power support from Hazelwood, by reducing the amount of reactive power injection to the transmission network from distribution networks. As a result of the investigation, about 270 megavolt amperes reactive (MVAr) of distribution capacitors have been switched off until at least the end of summer 2017-18.

However, even with switching off 270 MVAr of distribution capacitors, since March 2017 the need for de-energisation of 500 kV lines has increased significantly. So far, the de-energisation of 500 kV lines has been implemented more than 40 times during light load periods to manage high voltage, and de-energisation of two 500 kV lines has also been required five times during very light load periods.

The forecast minimum Victorian operational demand[3] (on a sent out basis) in 2018 is less than the threshold[4] below which 500 kV line de-energisation is expected to be implemented so that voltages can stay within operating limits after a contingency. With the forecast continued reduction in minimum operational demand, future de-energisation of single and two 500 kV lines is expected to be implemented more frequently, and potentially even de-energisation of three or more 500 kV lines may be required within the next five years. If no long-term permanent solution is implemented, this increased likelihood of 500 kV line de-energisation for managing high voltage will likely result in an increase in operational risks and/or market impacts. These risks and impacts are described below.

- Operational risks

  De-energisation of multiple 500 kV lines in Victoria is undesirable, because it reduces reliability of supply and increases difficulties in outage planning for maintenance. The 500 kV lines in Victoria form the backbone of the Victorian Transmission Network, and were not designed to operate with two or more 500 kV lines out of service under pre-contingency conditions. When two or more 500 kV lines are switched out of service for managing high voltages, any subsequent contingency could result in the power system losing stability, resulting in cascade tripping and large-scale interruption of consumers, even if the demand is low. While the likelihood of this high impact event is low at present, with an increased need for de-energisation of multiple 500 kV lines, the risk of this high impact event will increase in future if no long-term permanent solution is implemented.

- Market impacts

  De-energisation of 500 kV lines reduces Victoria's ability to export, and as a result, creates a market impact, as this increases the need for higher marginal cost generation in other regions. Typically, Victoria exports during light load periods, sending generation from brown coal power stations and renewables to other regions with higher priced generation. In future, with more renewables in Victoria under the Victorian Renewable Energy Target (VRET) and increasing frequency of need for 500 kV line de-energisation, a larger amount of low marginal cost plant will need to be constrained off for longer durations in Victoria, implying higher market impacts.

  AEMO's 2017 *Victorian Annual Planning Report* (VAPR) identified that the market benefit (from cost of fuel savings) by avoiding de-energisation of a single 500 kV line could be in the range of $7 million to $26 million over the next 40 years[5]. It is expected that the market benefit (from fuel cost savings) by avoiding de-energisation of multiple 500 kV lines could be higher.

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[3] See Section 3.1 for more information on the Victorian minimum operational demand forecasts.

[4] This threshold level is estimated to be approximately 3,250 MW for de-energising single 500kV circuit, and 2,900 MW for de-energising two 500kV circuit under system normal conditions when all primary network assets are in service, or higher if any relevant reactive power plant is out of service for maintenance.

[5] See Section 3.5 of AEMO's 2017 VAPR, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/VAPR/2017/2017-VICTORIAN-ANNUAL-PLANNING-REPORT.pdf.

Need for solutions

The observations mentioned above clearly indicate that there is a current need for additional reactive power support, to reduce the operational risks and market impact from 500 kV line de-energisation while keeping voltages within operational and design limits.

AEMO has undertaken power system studies to assess potential long-term solutions to meet the identified need. In the studies, AEMO assessed the voltage performance of the Victorian transmission system, based on a range of credible scenarios, and identified the locations where voltages exceed operational limits. AEMO then modelled reactive power plant with a range of capacities at various terminal stations to identify the most effective combination of locations/capacities.

The studies have found:

- To avoid 500 kV line de-energisation, additional absorbing reactive power support of approximately 350 MVAr, or equivalents in the form of non-network options, will be required in 2018.
- This need will increase to approximately 600 MVAr in total by 2021-22 and a further 200 MVAr by 2026-27.
- The most effective locations for installing the additional reactive power support include the existing Geelong, Moorabool, South Morang, Keilor, and Sydenham terminal stations.

The required additional reactive power support may be installed progressively towards 2027 in stages, with stage 1 installation to be implemented as soon as practical. The preferred option, the stages of implementation and the optimal timing of each stage will be assessed and proposed in the PADR.

These estimates of total capacity of additional absorbing reactive power support assume that no planned outage of the additional reactive power plant occur during light load periods. Further assessment will be carried out in the PADR to confirm the capacities of credible options.

AEMO will continue to explore operational and short-term solutions, including non-network solutions, to address the current need before a long-term solution can be implemented.

2.3 Classes of market benefit relevant to the RIT-T

The purpose of the RIT-T is to identify the preferred option to address the identified need that maximises the present value of the net economic market benefit to all those who produce, consume, and transport electricity in the market[6].

To satisfy the RIT-T, the present value of the net market benefit of implementing the preferred option must outweigh the cost of doing so.

AEMO believes the classes of market benefits most relevant to this RIT-T are:

- **Variable operating costs.**

  De-energisation of 500 kV lines has been used as an operational measure to manage the high voltages to date. However, this measure reduces network transfer capability on the backbone of the Victorian transmission network, resulting in reduced exports, which could lead to an increase in overall cost of generation. The implementation of augmentation options which can avoid or reduce the frequency of line de-energisation will achieve market benefit from reducing generation fuel cost.

- **Costs to other parties.**

  It is a security violation if voltages are not kept within the operating limits. Therefore, if no investment in a permanent solution is made via the RIT-T process, investment via another process will have to be made to avoid the security violation.

  In addition, any investment to address the identified need of this RIT-T could also reduce investment by other parties to address other needs. For example, the installation of synchronous condensers can also reduce the investment by generators to address system strength issues. The cost saving to other parties could include, but is not limited to:

  - Victorian DNSPs' costs in addressing high voltage issues in the distribution networks.
  - Generators' costs in addressing system strength issues.
  - AEMO's system operator costs in addressing high steady state voltage issues, voltage stability issue and system strength issues.

- **Timing of other transmission investment.**

[6] Refer to Clause 5.4.5B (b) of the NER.

Investment to address the identified need of this RIT-T could postpone other transmission investments, such as investments for meeting any additional system strength obligations on TNSPs introduced via recent Rules Changes[7] could be postponed by the installation of synchronous condenser to address the identified need of this RIT-T.

- **Voluntary load curtailment and involuntary load shedding.**

  The identified need of this RIT-T is related to reduction of reliability risk from the de-energisation of 500 kV lines. AEMO therefore expects that the market benefits from reducing voluntary load curtailment and involuntary load shedding is relevant to this RIT-T.

[7] See Clause 5.20 C in the final rules on AEMC's website at https://www.aemc.gov.au/sites/default/files/content/38cbd875-6295-4d8d-acd6-52d5adfc3041/System-Strength-Final-Rule-19-Sept-2017-VERSION-FOR-PUBLICATION.PDF.

3. Assumptions made in identifying the need

3.1 Minimum demand forecast

The identified need was assessed based on AEMO's minimum demand forecast[8]. As shown in Figure 1, this minimum demand forecast predicts a significant reduction in Victoria's operational minimum demand, from about 2,300 MW in 2017-18 to 500 MW in 2036-37 under the Neutral 90% probability of exceedance (POE) scenario[9]. This reduction is mainly driven by a significant forecast increase in rooftop solar PV installation, also shown in Figure 1 below.

Figure 1 Minimum demand and rooftop solar PV forecast

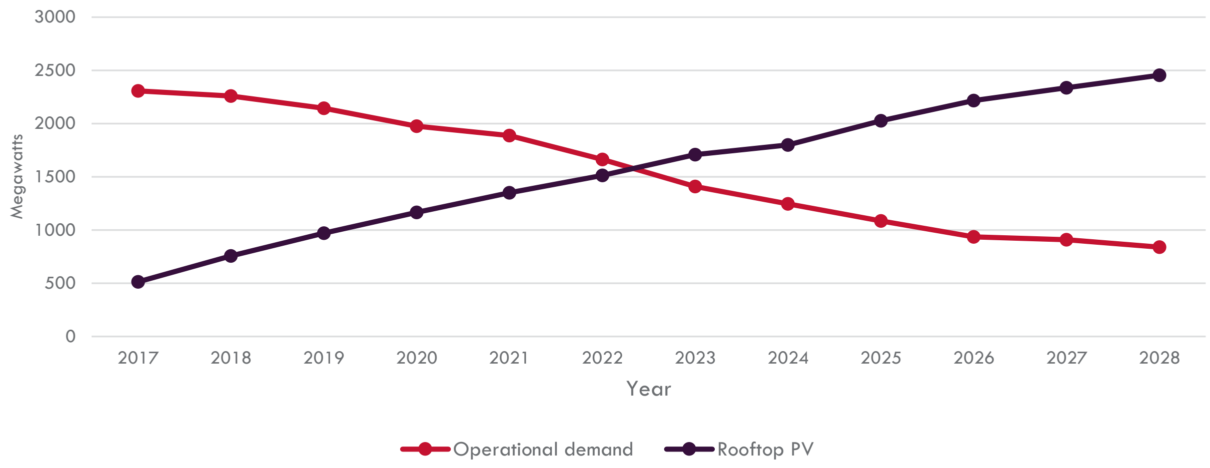


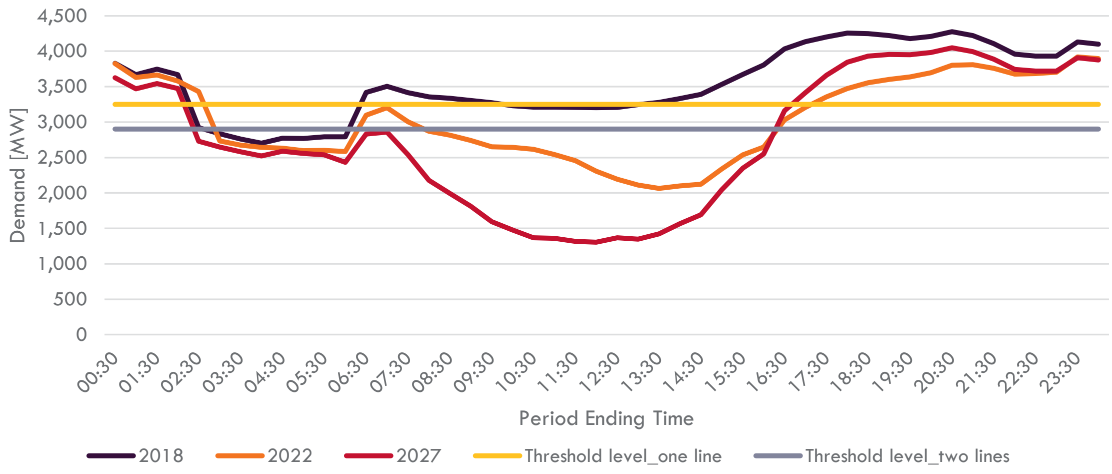
Figure 2 shows simulated daily regional demand profiles for the minimum demand days in 2018, 2022, and 2027 under the Neutral 50% POE scenario. These indicative profiles highlight the forecast minimum demand time shifting, from the current early morning minimum to a mid-day minimum in future. Similar to the minimum demand reduction, the shift in minimum demand time is mainly driven by an increase in rooftop solar PV installation.

Figure 2 also shows Victoria's indicative threshold demand levels for one line de-energisation and two line de-energisation (3,250 MW and 2900 MW respectively), and demonstrates that the duration when line de-energisation (particularly multiple line de-energisation) is required to manage high voltage violation will significantly increase in 2022 through to 2027.

[8] Based on AEMO's forecasts published in June 2017, available at http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Electricity-Forecasting-Insights/2017-Electricity-Forecasting-Insights/Summary-Forecasts/Maximum-and-minimum-demand.

[9] See AEMO's *Electricity Forecasting Insights* for more information on scenarios, on AEMO's website at http://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/EFI/2017-Electricity-Forecasting-Insights.pdf.

Figure 2 Simulated daily regional demand profiles of minimum demand days in 2018, 2022, and 2027, as well as Victorian demand thresholds for 500 kV line de-energisation



3.2 Connection point reactive load forecast

Connection point reactive power load forecasts are calculated using the active power forecasts and an estimate of the power factor for each connection point. For this RIT-T, power factors have been estimated based on the historical minimum demand in AEMO's Operational Planning Data Management System (OPDMS)[10].

Because minimum demand is expected to occur around mid-day in future due to greater solar rooftop solar PV penetration, a mid-day OPDMS snapshot corresponding to the historical minimum demand day in 2017 was used to estimate the power factors.

When the detailed study leading to this RIT-T started in August 2017, AEMO identified 17 April as the minimum demand day in 2017 after the Hazelwood Power Station closure. The results from the detailed study were spot checked and validated in early 2018 using a snapshot reflecting the observed 2017 annual minimum demand day in December 2017.

3.3 Forecast of generation expansion and dispatch pattern

This RIT-T considered all committed generation projects in Victoria according to the generation information page on AEMO's website[11].

In addition to the committed projects, this RIT-T also considered a number of wind farm projects which are expected to be committed in the near future. Given the Victorian Renewable Energy Target (VRET), AEMO considers it reasonable to assume that certain large-scale renewable generation projects will be built in Victoria, even if they are not fully committed at the time this report is prepared.

The forecast increase in renewable generation and the rapid reduction in minimum demand in Victoria due to high distributed energy resources (DER) penetration will result in the dispatch of less synchronous generation, and may lead to retirement of baseload plant. AEMO has carried out a sensitivity analysis to review the impact of less baseload generation on the identified need.

10 OPDMS is a database containing historical operational information.

11 See http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Generation-information. "Committed" is defined on each regional spreadsheet.

3.4 Reactive power support from renewable generation

Large-scale renewable generation

AEMO assumed no reactive power support from modelled large-scale renewable generation as a base case assumption in identifying the investment need. This base case assumption represents the worst case scenario.

The automatic access standard set out in clause S5.2.5.1 of the NER requires the plant to provide reactive power of 39.5% of active power output, and the minimum access standard allows generators with no capability to supply or absorb reactive power at the connection point. The reactive power capability requirement for a future renewable generation connection could be within a range between the automatic access standards and minimum access standards.

AEMO carried out a sensitivity analysis with a reactive power capability between the automatic access standard and the minimum access standard for new renewable generating units to review the impact of a change in this assumption on the identified need, to ensure the robustness of the identified need.

Rooftop solar PV installations

In calculating connection point reactive load, AEMO assumed that rooftop solar PV installations would also not provide any reactive power, consistent with the common performance of the existing rooftop solar PV installations.

AEMO recognises that future rooftop solar PV installations may be equipped with inverters which allow the solar PV installations to provide reactive power. A sensitivity analysis was carried out as part of this RIT-T, assuming new rooftop solar PV installations in areas with high voltage issues will be capable of providing reactive power support with a 0.97 power factor, to test the robustness of the identified need.

3.5 Non-standard operational measures

The following non-standard operational arrangements are considered as short-term solutions when identifying the need, together with standard operational measures such as transformer tapping, the use of available reactive plant, reactive capability of generating units, as well as contracts with existing generators or network service providers (NSP) for voltage support.

500 kV line de-energisation

The level of absorbing reactive power compensation required to meet the identified need was calculated assuming no de-energisation of 500 kV lines. This, and other possible operational measures, are intended to be reserved for more extreme and unexpected operating conditions.

Status of capacitor banks installed within distribution networks

The reactive power loads in the OPDMS minimum demand snapshot will change with the capacitors installed within the distribution network. Unlike the capacitors installed in the transmission network, which would be already switched off if over-voltage issues in the transmission network were observed, some distribution network connected capacitors may still be in service during these periods.

As noted above, as an outcome of joint planning between AEMO and DNSPs, an arrangement was made to ensure certain distribution capacitor banks will be switched off during preselected light load periods to manage the high voltage issue for the 2017-18 summer. The reactive power load forecasts used in this RIT-T reflect the effect of this arrangement through the use of historical information from ODPDMS snapshots.

AEMO performed a sensitivity analysis, with a reduced amount of distribution capacitors being switched off, to test the robustness of the identified need, as some of the switched-off distribution capacitors may be switched back in services in future during low demand periods.

4. Credible options to address the identified need

4.1 Description of credible network options

Credible network options to meet the identified need should have the capability to provide additional absorbing reactive power to the Victorian transmission network, such as the installation of reactive power plant (including reactors, Static VAr Compensators (SVCs), or synchronous condensers) at specified locations, voltage levels, types, capacities, and connection arrangements.

Locations

Power system studies have identified that the most effective locations for additional absorbing reactive power to manage high voltage issues in Moorabool, followed by South Morang, Sydenham, and Keilor.

The total additional absorbing reactive power required to manage over-voltages on the Victorian transmission network and avoid the de-energisation of 500kV line(s) is estimated to be 800 MVAr (600 MVAr by 2021-22 and an additional 200 MVAr by 2026-27) if installed at these locations.

Voltage levels

The most effective voltage levels for connecting additional reactive power plant are at 220 kV, 500 kV, or both. Connecting all additional reactive power plant to 66 kV is a credible option, but unlikely to be the preferred option, due to reduced effectiveness and higher overall cost (see Appendix A1 for building block prices). Therefore, connecting solely at 66 kV has not been considered further in this RIT-T.

Type of reactive power plant

Both reactors and dynamic type of reactive power plant can be used to meed the identified need. Dynamic plant includes SVCs, synchronous condensers, and any other plant which can provide continuously varying reactive power support.

Dynamic reactive power plant is more expensive than reactors, but can provide benefits which reactors cannot provide, such as improving system strength and voltage stability. Also, it is a common industrial practice to keep a reasonable amount of dynamic reactive power plant in a highly compensated network (that is, a network with a lot of reactors and capacitors) to manage operational issues such as large step voltage changes following switching of large reactors or capacitors.

An option, with a combination of shunt reactors and dynamic reactive power plant, is included in this PSCR for further assessment in PADR. In the PADR, AEMO will carry out further studies to assess the benefits from dynamic reactive power plant in addition to keeping voltage levels within operational and design limits.

Capacity (MVAr) of reactive power plant

A given amount of reactive power requirement can be met by using a small number of high capacity reactive power plant, or a large number of low capacity reactive power plant. The use of high capacity reactive plant is typically more cost-effective than the use of low capacity plant, if only considering system normal conditions. However, considering operational issues associated with switching high capacity plant, and the need for maintenance, the capacity of reactive power plant will need to be carefully selected to achieve the most cost-effective outcome.

In this PSCR, the following are considered as the standard capacities for reactors for the purpose of developing cost estimates for the network options:

- 50 MVAr at 66kV.
- 100 MVAr at 220 kV.
- 200 MVAr at 500 kV (100 MVAr will be used if the use of 200 MVAr will exceed the total requirement).

A ±100 MVAr dynamic plant is considered as the standard capacity for a 220 kV dynamic reactive plant.

These standard capacities have been selected to align with existing or retired reactive plant in the Victorian transmission network, given certainty on their technical feasibility. Non-standard capacities could be assessed in PADR, if proven beneficial, to ensure all credible options are considered in the RIT-T.

Connection arrangements

A number of connection arrangements will need to be considered in detail, including:

- **Standard arrangement (single-switching).**

  The standard arrangement for connecting reactive plant to the Victorian transmission network is a single switched arrangement, where the reactive power plant is connected to a bus with a single circuit breaker.

- **'Line shunt' arrangement (where a new reactive power plant is connected to one or both ends of a line behind the line circuit breaker).**

  With this special arrangement, no new circuit breaker will be required for the new reactor, because the reactor will share the line circuit breaker. This special arrangement is typically used to compensate line charging during light load periods for long transmission lines, but can also be considered for connecting reactive plant.

  While this special arrangement can reduce costs associated with new circuit breakers, it may not reduce the overall cost, because it tends to increase the total amount of additional reactive power requirement to cover for a maintenance of the line with the line shunt reactive power plant. This is because line maintenances will normally be scheduled during light load periods, and the reactive plant with this special arrangement may not be available during line maintenance. The concurrent outage of line/reactive plant under this special arrangement will also incur operational cost and reliability impacts.

  This arrangement will be further assessed in the PADR, before it is considered as a candidate to be the preferred option.

- **'Bus-shunt' arrangement.**

  There are currently two 100 MVAr line reactors associated with Tarrone – Alcoa Portland (APD) and Mortlake – APD 500 kV lines respectively. Each of these reactors will trip together with its associated 500 kV line. Power system studies have indicated that if the reactor remains in service following a 500 kV line tripping, the additional absorbing reactive power requirement could be reduced by approximately 60-70 MVAr for the scenarios with APD load in service. This is because the trip of these two 500 kV lines together with APD load is a critical contingency associated with the identified need for this RIT-T.

  A potential special arrangement for additional absorbing reactive power is to change the existing arrangement of connecting 500 kV APD reactors from 'line shunt' to 'bus shunt', which can provide an equivalent of 60-70 MVAr absorbing reactive power support by installing two new 500 kV circuit breakers. This change will also tend to reduce operational cost and improve reliability, by adding flexibility in operating the line and the reactors separately and avoid tripping both line and reactor by a single fault. While there are benefits to the change from 'line shunt' to 'bus shunt', further assessment in the PADR will be required to ensure this change is technically and financially feasible, considering the age and condition of the existing reactors.

4.2 Potential network options and cost estimates

Possible network options (at a high level) to meet the identified need include:

- Option 1 – A combination of reactors with different sizes and at various voltage levels.
- Option 2 – A combination of reactors with a single dynamic reactive plant.
- Option 3– A combination of reactors with two dynamic reactive plant.

Considering the possible combined permutations of the options, it is impractical to include all potential credible network options in cost estimates. In this report, AEMO has only developed a cost estimate (±50%) of one possible variant of each of the above network options, which is considered the most like variant for that option. See Tables 1-3 for the cost estimates of the variants.

The cost estimates in the report are based on standard capacities of reactive power plant and standard connection arrangements (see Section 4.1). Building block prices for the reactive power plant and associated circuit breakers as assumed in this report are given in Appendix A1.

The typical lead time is 12-18 months for installing reactors, and 18-36 months for installing synchronous condensers. The actual time required will depend on many factors, such as the location of the manufacturer, whether they are made to order or off-the-shelf products, and the location of the installations.

AEMO will further investigate any practicality issues, such as site-specific requirements at the relevant location as part of the PADR. AEMO will also further assess the impact on system performance of switching large capacity reactors, and the use of smaller capacity reactors or dynamic reactive plant to mitigate the impact, taking into account any real-time operational issues AEMO has experienced in switching the existing large capacity reactors. The actual capacities, locations, and estimated costs of the options may be fine-tuned in the PADR, based on further investigations by AEMO.

Table 1 Option 1 – 500 kV and 220 kV shunt reactors

Stage	Description	Total MVAr	Estimated Price($M)
1	500 kV 1 x 200 MVAr Shunt Reactor at Moorabool 500 kV 1 x 200 MVAr Shunt Reactor at South Morang 220 kV 2 x 100 MVAr Shunt Reactor at Geelong	600	24.4
2	220 kV 2 x 100 MVAr shunt reactor at South Morang	200	8.2
Total		800	32.6

Table 2 Option 2 – shunt reactors and one synchronous condenser

Stage	Description	Total MVAr	Estimated Price($M)
1	500 kV 1 x 200 MVAr Shunt Reactor at Moorabool; 500 kV 1 X 200 MVAr Shunt Reactor at Keilor 200 kV 1 x 100 MVAr shunt reactor at South Morang 220 kV 1 X ±100 MVAr Synchronous Condenser at Moorabool	600	30.4
2	500 kV 1 x 200 MVAr Shunt Reactor at South Morang	200	8.1
Total		800	38.5

Table 3 Option 3 – shunt reactors and two synchronous condensers

Stage	Description	Total MVAr	Estimated Price($M)
1	500 kV 1 x 200 MVAr Shunt Reactor at Moorabool; 500 kV 1 X 200 MVAr Shunt Reactor at Keilor 200 kV 1 x ±100 MVAr Synchronous Condenser at Geelong 220 kV 1 X ±100 MVAr Synchronous Condenser at Moorabool	600	36.4
2	500 kV 1 x 200 MVAr Shunt Reactor at South Morang	200	8.1
Total		800	44.5

4.3 Non-network options

A suite of non-network options may be available for meeting or partially meeting the identified need, including:

- **Demand response and decentralised storage.**

The demand level during low demand periods can be increased by encouraging and promoting demand response, load shifting, and co-ordinated charging of decentralised storage. It is conceptually possible to increase the demand during light load periods when a high voltage violation is expected to occur, by utilising flexible loads such as hot water, underfloor heating, and pool pumps, in addition to emerging flexible loads such as EVs and distributed storage. An effective load increase at times of low demand is an alternative to the provision of additional absorbing reactive power in addressing the identified need.

AEMO is not aware of any practical means of providing sufficient load increase such as big pump loads or battery charging at appropriate connection points, during periods of light load and high network voltages at present, and is seeking information from potential providers of this type of non-network service. See Section 4.3.1 for details of the information AEMO is seeking.

- **Additional absorbing reactive power capability from grid-connected generators.**

  All grid-connected generators have a requirement to supply reactive power in accordance with agreed performance standards. Any generators with an absorbing reactive power capability higher than the requirement stipulated in the agreed performance standards could provide the spare absorbing reactive power capability to meet or partially meet the identified need, and delay or remove the need for investment in network options.

  AEMO is seeking information from generators and other parties with additional absorbing reactive power capabilities, or equivalent, for meeting the identified need. See Section 4.3.1 for details of the information AEMO is seeking.

- **Solar rooftop PV reactive power support.**

  New types of inverters installed with rooftop PV may be capable of providing reactive power support, both generating and absorbing. The identified need could be met by aggregating and dispatching the absorbing reactive power from these inverters. The dispatching of the aggregated absorbing reactive power support from rooftop solar PV inverters have a similar effect to increasing reactive power loads to suppress high voltages in the transmission network.

  AEMO is not aware of any practical means of aggregating and dispatching sufficient absorbing reactive power support from rooftop solar PV installations during periods of light load and high network voltages at present, and is seeking information from potential providers of this type of non-network services. See Section 4.3.1 for more details on the information AEMO is seeking.

4.3.1 Information to be provided by proponents of a non-network option

The above is not an exhaustive list of non-network services. AEMO would welcome proponents of non-network options to make submissions on any non-market ancillary services (NMAS) they can provide to address the identified need outlined in this PSCR.

Submissions should include details on:

- Organisational information.
- Relevant experience.
- Details of the service.
- Cost of service, separating capital and operational expenditure.
- Confirmation of timelines in providing the service.

5. Materiality of market benefits

AEMO notes the NER requirement that all categories of market benefit identified in relation to the RIT-T are included in the RIT-T assessment, unless the TNSP can demonstrate that:

- A specific class (or classes) of market benefit are unlikely to be material in relation to the RIT-T assessment for a specific option.
- The cost of undertaking the analysis to quantify that benefit would likely be disproportionate to the "scale, size and potential benefits of each credible option being considered in the report".

AEMO considers that the following classes of market benefits are not material to the RIT-T assessment for any of the credible options:

- **Network losses.**

  The identified need of this RIT-T is related to suppression of high voltages during light load periods. While augmentation options to suppress high voltages could marginally increase network losses, it is not expected the increase will be material in relation to the RIT-T assessment for a specific option, as all options which can suppress high voltage will have similar (small) impact on network losses.

- **Changes in ancillary services costs.**

  There is no expected change to the costs of frequency control ancillary services (FCAS), network control ancillary services (NCAS), and system restart ancillary services (SRAS) as a result of the augmentation options being considered. These costs are therefore not material to the outcome of the RIT-T assessment.

- **Competition benefits.**

  Competition benefits are not expected to be material to the outcome of this RIT-T assessment. The high voltages are localised in nature and have a limited impact on spot market outcomes except when line de-energisation is used to manage the issue. It is expected that all options which can suppress high voltage will have a similar (small) impact on spot market outcomes. The estimation of any competition benefit in this RIT-T assessment would require significant modelling which would be disproportionate to any competition benefits arising from any of the credible options in this RIT-T.

- **Option value.**

  For this RIT-T assessment, the estimation of any option value benefit over and above that already captured via the scenario analysis in the RIT-T would require a significant modelling, which would be disproportionate to any additional option value benefit that may be identified for this specific RIT-T assessment. In this case, appropriate identification of credible options and reasonable scenarios should capture any option value. AEMO does not therefore propose to estimate any additional option value market benefit for this RIT-T assessment.

A1. Building block costs of reactive power plant and associated circuit breakers

Table 4 Unit costs of reactive plant and associated equipment used in estimating costs of options

Equipment	Voltage level	Rating	Unit cost ($M)
Shunt reactor	500 kV	200 MVAr	5.2
	500 kV	100 MVAr	4.4
	220 kV	100 MVAr	3.0
	66 kV	50 MVAr	1.9
Circuit breaker	500 kV	4,000 Amps	2.9
	220 kV	3,150 Amps	1.1
	66 kV	3,150 Amps	0.8
Synchronous condenser*	11 kV	±100 MVAr	10

* The cost of a step up transformer 11/220 kV is included in the unit cost for a synchronous condenser.