# AusNet Transmission Group Pty Ltd

## Transmission Revenue Review 2017-2022

## Support Document: Planning Report Templestowe Terminal Station (Public)

**Submitted: 30 October 2015**

# AMS – Electricity Transmission Network

## Planning Report Project XC15

## Templestowe Terminal Station Transformer and Circuit Breaker Replacement

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# 1 Executive Summary

## 1.1 Responsibility

AusNet Transmission Group (AusNet Services) as a Transmission Network Service Provider (TNSP) in the state of Victoria has the ownership, operation and maintenance responsibility for Templestowe Terminal Station (TSTS). TNSP obligations include maintaining a safe working environment for staff and contractors, maintaining the quality, reliability and security of customer supplies, and preventing operating and maintenance costs from escalating to inefficient levels.

## 1.2 Emerging Constraints

The majority of the electricity assets at TSTS are more than 45 years old and condition assessments indicate that several assets are approaching the end of their technical lives. The emerging service constraints are:

- Health and safety risks presented by a possible explosive failure of instrument transformers, 66 kV bulk oil circuit breakers or transformer bushings;
- Security of supply risks presented by a failure of the 220/66 kV transformers or 66 kV circuit breakers;
- Collateral plant damage risks presented by an explosive failure of a transformer bushing, instrument transformer or bulk oil circuit breaker bushing;
- Environmental risks associated with insulating oil spill or fire.

## 1.3 Economic Option

This planning study considers credible options to address the service constraints and to meet the long term planning requirements for TSTS outlined in the Victorian Annual Planning Report (VAPR) and Transmission Connection Planning Report (TCPR). The options that have been assessed are:

- Business as usual to define the baseline risk;
- Non network option of embedded generation and/or demand side response;
- Run to failure and replace assets upon failure;
- Integrated replacement;
- Staged replacement;

The most economic option to address the emerging constraints at TSTS is an integrated redevelopment with AIS that replaces all deteriorating assets and addresses all emerging risks. This option has the lowest present value cost ($34.2M) and is consistent with the future development plans for TSTS. The economic timing for project completion is before Summer 2020/21 with an estimated total capital cost of $34.2 M ($29.0 M direct 2015).

# 2 Purpose

This planning report outlines asset condition, asset failure risks and network development plans relevant to TSTS for the planning period from 2015/16 to 2024/25. It provides an analysis of viable options to address the identified risks and maintain the efficient delivery of electrical energy from TSTS consistent with the National Electricity Rules (NER) and stakeholder's requirements. It also summarizes the scope, delivery schedule and expenditures associated with the most economical solution to emerging constraints.

# 3 Regulatory Obligations and Customer Requirements

This planning report acknowledges AusNet Services' obligations as a TNSP under the National Electricity Rules with particular emphasis on:

Clause 6A.6.7 of the National Electricity Rules requires AusNet Services to propose capital expenditures necessary to:

*(1) meet or manage the expected demand for prescribed transmission services over that period;*

*(2) comply with all applicable regulatory obligations or requirements associated with the provision of prescribed transmission services;*

*(3) to the extent that there is no applicable regulatory obligation or requirement in relation to:*

*(i) the quality, reliability or security of supply of prescribed transmission services; or*

*(ii) the reliability or security of the transmission system through the supply of prescribed transmission services,*

*to the relevant extent:*

*(iii) maintain the quality, reliability and security of supply of prescribed transmission services; and*

*(iv) maintain the reliability and security of the transmission system through the supply of prescribed transmission services; and*

*(4) maintain the safety of the transmission system through the supply of prescribed transmission services.*

The Electricity Safety Act (section 98(a)) requires AusNet Services to "design, construct, operate, maintain and decommission its supply network to minimise the hazards and risks, so far as is practicable, to the safety of any person arising from the supply network; having regard to the:

*a) severity of the hazard or risk in question; and*

*b) state of knowledge about the hazard or risk and any ways of removing or mitigating the hazard or risk; and*

*c) availability and suitability of ways to remove or mitigate the hazard or risk; and*

*d) cost of removing or mitigating the hazard or risk".*

# 4 Background

TSTS is located approximately 25km north-east from Melbourne's CBD, (Melway map reference 34 E-2) and is the main source of supply for a major part of north-eastern metropolitan Melbourne. The TSTS supply area spans from Eltham in the north to Canterbury in the south and from Mitcham in the east to Kew in the West.

TSTS is supplied from Rowville Terminal Station (ROTS) and Thomastown Terminal Station (TTS) as shown in Figure 1.

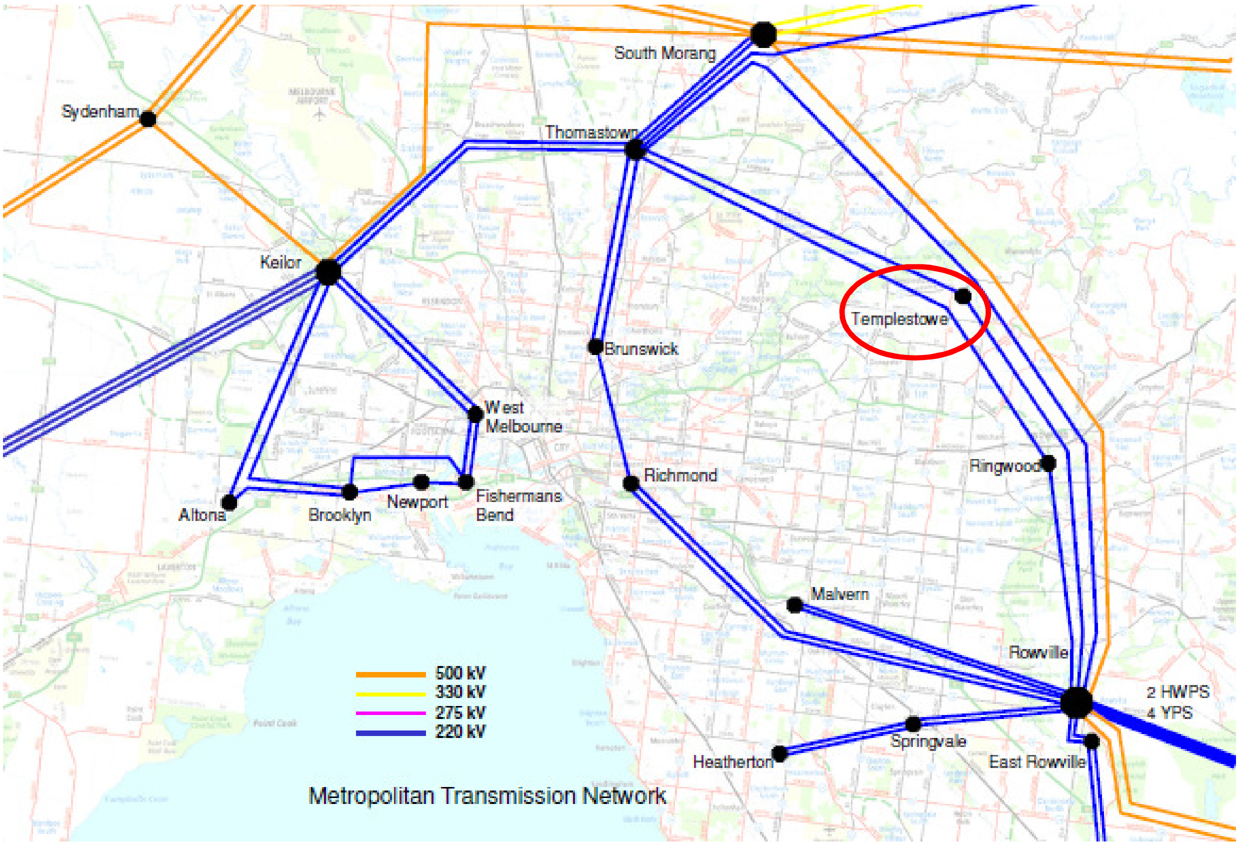


Figure 1 – Metropolitan Melbourne Transmission Network

TSTS has three 150 MVA 220/66 kV transformers. The B2 transformer was installed in 1966 and the B3 unit in 1968. A third transformer was installed in the early 1980s. The B2 and B3 transformers are connected directly to the No. 2 and No. 1 220 kV busbars respectively. The three 220/66 kV transformers provide transmission connection services to the distribution network service providers United Energy, CitiPower, AusNet Electricity Services and Jemena Electricity Networks.

One of the three Victorian synchronous condensers (SCO) is located at TSTS to provide dynamic reactive support to the transmission system.

Most of the 220 kV circuit breakers and current transformers at TSTS have been replaced.

The 66 kV switchyard includes nine feeders, three busbars, three bus-ties and a 50 MVAr capacitor bank. The transformer circuit breakers, feeder circuit breakers and bus-tie circuit breakers are bulk oil circuit breakers. The only exceptions are the two minimum oil circuit breakers (Feeder WD and 1-4 bus-tie) and the more recently installed SF6 circuit breakers protecting the BU and DC No. 2 feeders and the capacitor bank circuit breaker.

Many of the primary and secondary assets installed at the time that TSTS was established have deteriorated and are reaching the end of their technical lives. The risks associated with plant failure are increasing and these assets are becoming more difficult and expensive to maintain due to a lack of manufacturer support and a scarcity of spare parts.

Figure 2, below shows the present configuration at TSTS.

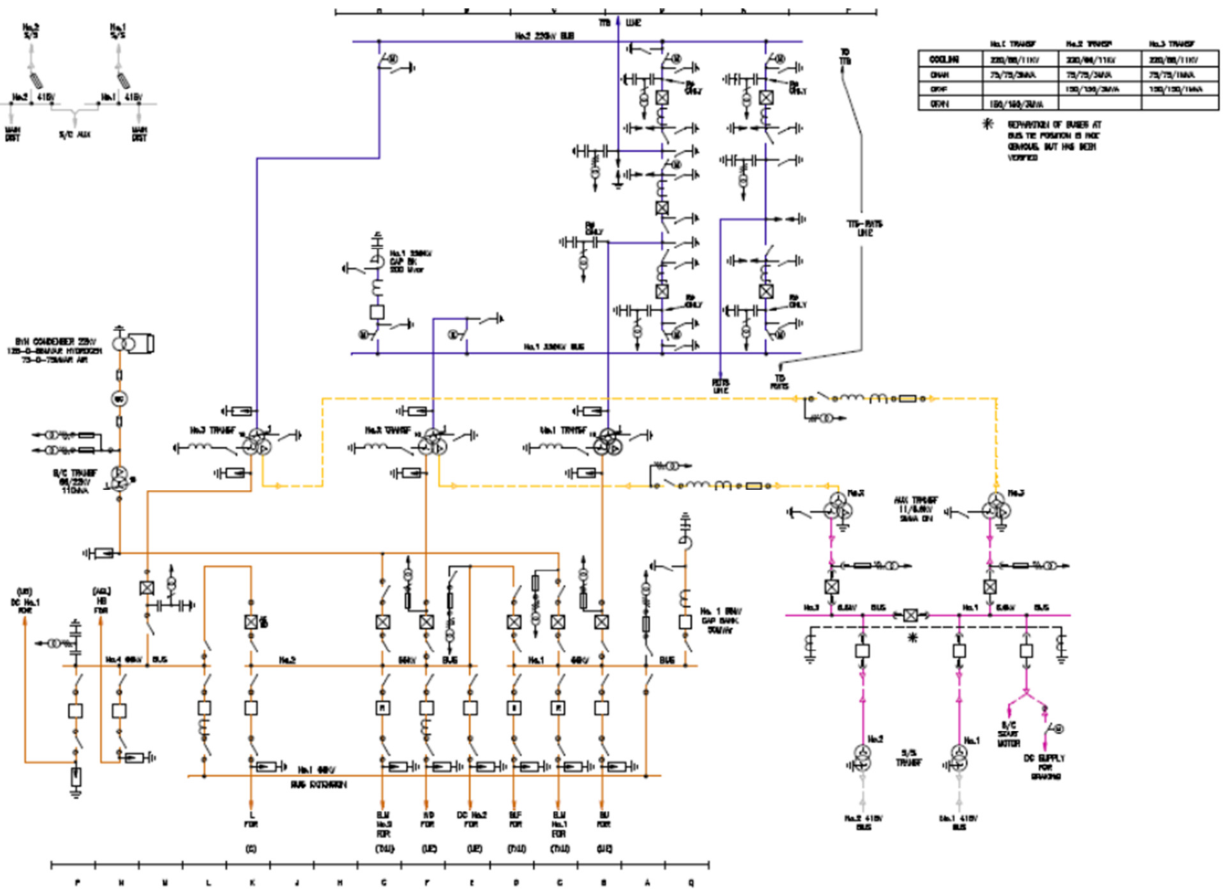

Figure 2 – Single Line Diagram of TSTS

# 5 Planning Considerations

## 5.1 Planning Responsibilities

The augmentation responsibility for TSTS resides with the Australian Energy Market Operator (AEMO) for the shared transmission network and with the distributors, United Energy, CitiPower, AusNet Electricity Services and Jemena Electricity Networks, for the transmission connection assets.

## 5.2 Demand Forecast

TSTS 66 kV is a summer peaking station and demand is forecast to grow at a low rate over the planning period. Figure 3 shows the forecast demand for Summer POE10 and POE50, and Winter POE50 conditions as prepared by the Distribution Businesses. The Distribution Businesses' demand forecast shows growth at an average annual rate of 1.2% and 0.9% for the Summer POE10 and POE50 forecasts respectively.

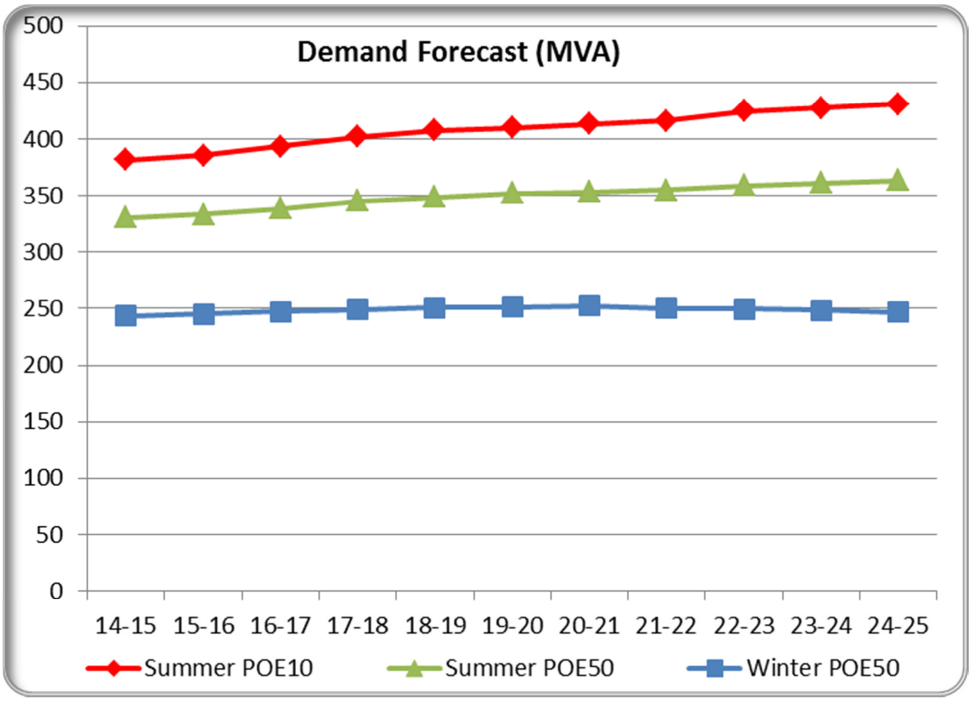


Figure 3 –Distribution Business demand Forecast for TSTS

## 5.3 Future Planning Requirements

Any significant asset replacements at TSTS must consider the longer term shared network and connection network development plans of other parties to ensure individual decisions will not compromise security of supply or impede economic future capacity augmentation. AusNet Services' redevelopment project accommodates AEMO and the distributors' future plans for TSTS, which include the following:

- 500 kV development with 500/220 kV transformation
- Fourth 150 MVA 220/66 kV transformer
- Provision for two more 220 kV lines
- Provision for two more 66 kV feeders

# 6 Asset Condition

AMS 10-13 Condition Monitoring describes AusNet Services' strategy and approach to monitoring the condition of assets as summarised in this section. Asset condition is measured with reference to an asset health index, on a scale of C1 to C5. The C1 to C5 condition range is consistent across asset types and relates to the remaining service potential. The table below provides a simple explanation of the asset condition scores.

| Condition Score | Likert Scale | Condition Description | Recommended Action | Remaining Service Potential% |
|---|---|---|---|---|
| C1 | Very Good | Initial Service Condition | No additional specific actions required, continue routine maintenance and condition monitoring | 95 |
| C2 | Good | Better than normal for age or refurbished | | 70 |
| C3 | Average | Normal condition for age | | 45 |
| C4 | Poor | Advanced Deterioration | Remedial action/replacement within 2-10 years | 25 |
| C5 | Very Poor | Extreme deterioration approaching end of life | Remedial action/replacement within 1-5 years | 15 |

Table 1 – Condition Score and Remaining Service Potential

Asset condition is the main driver for this project. The condition of the key assets at TSTS is discussed in the Asset Health Reports for the key asset classes such as power transformers, instrument transformers and switchgear with information on asset condition rankings, recommended risk mitigation options and replacement timeframes.

## 6.1 220/66 kV Power Transformers

AMS 10-67 Power Transformers and Oil-Filled Reactors describes AusNet Services' asset management strategy for power transformers and oil-filled reactors. The condition of the three 150 MVA 220/66 kV transformers at TSTS has been assessed according to AMS 10-67 and is shown in Table 2.

| DESCRIPTION | MANUFACTURER | INSTALL YEAR | End of Life Score | Core & Windings | Bushings | Oil | Tap Changer | Tank/Aux |
|---|---|---|---|---|---|---|---|---|
| B1 220/66KV | [C-I-C] | 1984 | 2 | 2 | 2 | 2 | 3 | 2 |
| B2 220/66KV | [C-I-C] | 1966 | 4 | 4 | 4 | 4 | 4 | 4 |
| B3 220/66KV | [C-I-C] | 1968 | 3 | 3 | 4 | 3 | 3 | 4 |

Table 2 – Transformer Condition Score

AMS 10-141 identifies a number of [C-I-C] 150 MVA transformers at various terminal stations as displaying a high level of internal ageing. The reasons for such deterioration are predominantly due to:

- High average loading and operating temperatures during high ambient temperatures
- Ineffective operation of high efficiency oil and air cooling systems

Condition deterioration is so great in these transformers that refurbishment is no longer a cost effective option. The B2 transformer is of a similar specification to those discussed in AMS10-141 and has been assessed as “Advanced deterioration” with an asset condition score of C4.

AusNet Services has outlined the objective to maintain a sustainable risk position for the next decade with respect to power transformers in AMS 10-67. The economic and technical merit to replace the B2 transformer in the next ten year planning period is therefore considered in this planning report.

A major transformer failure as result of a winding failure, major tap changer failure or bushing failure resulting in an extended transformer outage of months for major repairs or replacement is estimated to have a probability of between 3.4% to 5.2% over the planning period until 2022.

## 6.2 Station Service Transformers and 6.6 kV Switchboard

The two station service transformers at TSTS are of the same vintage as the B2 transformer and were installed in 1965. Condition assessments indicate that they are at the end of their useful technical lives. The station AC supply at TSTS depends on these two transformers. They are connected to a 6.6 kV common bus that is also very old and that has no arc fault capability, no reclose capability and no longer meets the modern day safety requirements. Any fault in this bus would affect the Synchronous Condenser (SCO) performance which provides dynamic reactive support to the shared transmission network. At present both station service transformers are supplied by two auxiliary transformers that are connected to the tertiary windings of the B2 and B3 transformers.

## 6.3 220 kV Circuit Breakers

The 220 kV circuit breakers at TSTS are all in good condition and their condition scores are shown in Table 3.

| CIRCUIT | MANUFACTURER | AGE | ASSET CONDITION |
|---|---|---|---|
| ROTS 220KV LINE NO.1 BUS CB AT TSTS | [C-I-C] | 15 | C3 |
| NO.1 220KV CAPACITOR BANK CB AT TSTS | [C-I-C] | 19 | C2 |
| B1 TRANS NO.1 BUS 220KV CB AT TSTS | [C-I-C] | 15 | C2 |
| ROTS 220KV LINE NO.2 BUS CB AT TSTS | [C-I-C] | 15 | C2 |
| TTS LINE/B1 TRANS 220KV CB AT TSTS | [C-I-C] | 15 | C2 |
| TTS 220KV LINE NO.2 BUS CB AT TSTS | [C-I-C] | 15 | C1 |

Table 3 – 220 kV Circuit Breaker Condition Score

## 6.4 66 kV Circuit Breakers

Thirteen of the eighteen 66 kV circuit breakers at TSTS are bulk-oil circuit breakers, three are SF6 gas insulated circuit breakers and two are minimum oil circuit breakers.

The bulk-oil circuit breakers are amongst the oldest circuit breakers installed in the network, ranging in service age from 47 to 49 years old. Asset Management Strategy AMS 10-106[1] provides a summary of the key issues of this type of circuit breakers, which includes the following:

- Age/duty related deterioration including the erosion of arc control devices, bushing oil leakages, and wear of operating mechanisms and drive systems;

1 AMS 10-106 Circuit Breakers.

- Limited fault level capability requiring restrictive switching configurations;
- Maintenance intensive;
- Manufacturer no-longer provides technical support or spares;
- Insufficient oil bunding.

The condition of the bulk oil circuit breakers has been assessed as C4 "Advanced deterioration" as indicated in Table 4.

| CIRCUIT | MANUFACTURER | AGE | ASSET CONDITION |
|---|---|---|---|
| B1 TRANS 66KV CB AT TSTS | [C-I-C] | 49 | C4 |
| 1-2 66KV BUS TIE CB AT TSTS | [C-I-C] | 49 | C4 |
| B2 TRANS 66KV CB AT TSTS | [C-I-C] | 49 | C4 |
| SYN/COND TRANS NO.1 BUS 66KV CB AT TSTS | [C-I-C] | 48 | C4 |
| SYN/COND TRANS NO.2 BUS 66KV CB AT TSTS | [C-I-C] | 48 | C4 |
| DC NO.1 66KV FDR CB AT TSTS | [C-I-C] | 47 | C4 |
| ELM NO.2 66KV FDR CB AT TSTS | [C-I-C] | 47 | C4 |
| ELM NO.1 66KV FDR CB AT TSTS | [C-I-C] | 47 | C4 |
| HB 66KV FDR CB AT TSTS | [C-I-C] | 47 | C4 |
| L 66KV FDR CB AT TSTS | [C-I-C] | 47 | C4 |
| SLF 66KV FDR CB AT TSTS | [C-I-C] | 47 | C4 |
| 2-4 66KV BUS TIE CB AT TSTS | [C-I-C] | 47 | C4 |
| B3 TRANS 66KV CB AT TSTS | [C-I-C] | 47 | C4 |
| 1-4 66KV BUS TIE CB AT TSTS | [C-I-C] | 30 | C4 |
| WD 66KV FDR CB AT TSTS | [C-I-C] | 49 | C3 |
| NO.1 66KV CAPACITOR BANK CB AT TSTS | [C-I-C] | 13 | C2 |
| BU 66KV FDR CB AT TSTS | [C-I-C] | 11 | C1 |
| DC NO.2 66KV FDR CB AT TSTS | [C-I-C] | 11 | C1 |

Table 4 – 66 kV Circuit Breaker Condition Score

## 6.5 66 kV Current Transformers

There are six [C-I-C] 66 kV post-type current transformers installed at TSTS. As described in AMS 10-64[2], [C-I-C] current transformers of various operating voltages are demonstrating thermal and partial discharge issues in conjunction with declining dissolved gas analysis (DGA) results. Investigations indicate that the [C-I-C] current transformers show a design/manufacturing deficiency in the capacitive voltage grading structure of the insulation and the earth screen grounding connection. It is thought that electrical switching or lightning transient currents passing through the capacitive structure create an over-voltage condition that punctures the last few capacitive layers to earth. Partial discharge then continues to degrade the installation until cascade insulation failure occurs. The degradation of the insulation can rapidly advance causing explosive failure, resulting in human safety concerns, damage to adjacent equipment and long unplanned outages of network plant.

AusNet Services' asset management strategy is to replace [C-I-C] current transformers as they present a risk to network reliability, as well as a safety risk to personnel as some failure modes include explosion and fire. [C-I-C] current transformers (all voltage levels) have been monitored closely in recent times due to the explosive failure nature and safety risk they present. At least two [C-I-C] current transformers have failed explosively in the

2 AMS 10-64 Instrument Transformers.

Victorian transmission network over the last ten years[3]. In an effort to prevent further explosive failures many units have been replaced as a result of frequent monitoring, which revealed accelerated deterioration and imminent failure.

The [C-I-C] current transformers have a high and increasing cost of ownership due to regular oil sampling and analysis and the partial discharge condition monitoring necessary to manage the risk of an explosive failure. Table 5 shows the asset condition of the 66 kV [C-I-C] current transformers at TSTS.

| CIRCUIT | MANUFACTURER | AGE | ASSET CONDITION |
|---|---|---|---|
| WD 66KV FDR CB CT R/PH AT TSTS | [C-I-C] | 48 | **C4** |
| 1-4 66KV BUS TIE CB CT R/PH AT TSTS | [C-I-C] | 21 | **C4** |
| 1-4 66KV BUS TIE CB CT W/PH AT TSTS | [C-I-C] | 28 | **C4** |
| 1-4 66KV BUS TIE CB CT B/PH AT TSTS | [C-I-C] | 29 | **C4** |
| WD 66KV FDR CB CT W/PH AT TSTS | [C-I-C] | 29 | **C4** |
| WD 66KV FDR CB CT B/PH AT TSTS | [C-I-C] | 21 | **C4** |

Table 5 – 66 kV Current Transformer Condition Score

## 6.6 Secondary Systems

The protection and control systems at TSTS consist of varied technologies. Some of the electromechanical type relays originally installed are still in service. Over the years, protection system upgrades for specific primary assets have been necessary, resulting in the existence of first generation digital relays as well as some newer protection equipment. These targeted protection system replacements have resulted in a hybrid protection configuration where the station's mimic panel is still partly used. The electromechanical and first generation digital relays have mal-operated in the past and have reached the end of their technical lives. The lack of a proper serial link to HMI with Remote Telemetry Unit (RTU) makes operation and maintenance challenging and more risky in network contingency situations. Interfacing the existing equipment with new protection systems required for new primary plant will further complicate the non-standard protection system configuration at TSTS and increase the associated operation and maintenance costs and risks.

Performance and maintenance issues associated with both the transformer and transformer zone protection schemes currently in service at TSTS reinforce the need for replacement of these schemes coincident with transformer and circuit breaker replacements. In particular, replacement of the existing medium impedance zone differential protection schemes associated with the TSTS transformers by high or low impedance schemes will help to improve the stability and reliability of the zone protection schemes, whilst replacement of the two winding DUO BIAS and RADSB biased differential protection relays associated with all three 220/66 kV transformers by three winding protection relays will improve transformer protection sensitivity.

Circuit breaker replacement represents an opportunity to introduce modern circuit breaker management schemes in place of the existing, ageing CAG-based circuit breaker fail schemes and hardwired circuit breaker control infrastructure, in line with AusNet Services, secondary asset management strategies.

3 In 2002 and 2005 at Moorabool Terminal Station (MLTS).

# 7 Emerging Constraints

The key service constraints and monetised risk identified for the aging and deteriorated assets at TSTS are described in this section.

## 7.1 Safety and Environmental Hazards

### 7.1.1 Transformers

Transformers B2, B3 and the SCO transformer at TSTS have synthetic resin bonded paper (SRBP) bushings. As described in AMS 10-67 Power Transformers and Oil Filled Reactors these bushings are of an obsolete design. Condition assessments indicate de-lamination of the SRBP core in several bushings on these transformers resulting in oil draining from the bushing into the transformer main tank. Rigorous monitoring of oil levels to close tolerances and frequent transformer outages are required to maintain oil conservator levels and to replace the oil lost from the bushings to prevent the ingress of moisture and subsequent bushing failure.

The failure of a transformer bushing could cause a fire and some of these type of failures have resulted in the complete destruction of the transformer plus damage to other equipment. AusNet Services' network experienced 220 kV bushing failures and transformer fires in 1965 and 1987 at Dederang Terminal Station from this failure mechanism. Four recent interstate bushing failures in Queensland and New South have involved complete transformer failures. These failure modes present a safety risk to personnel working in the vicinity of the transformer due to the nature of the failure which could sometimes result in projectiles or oil fires.

AusNet Services has initiated two refurbishment projects X417[4] (Stage 1) and Project X834[5] (Stage 2) to replace this type of bushing on transformers where other key transformer components including the 'core and coils' are in sound condition and additional transformer service life is probable. The poor core and coil condition of the TSTS B2 and SCO transformer suggests that bushing replacement is not economic on these transformers.

### 7.1.2 Circuit Breakers

Most of the 66 kV circuit breakers at TSTS are bulk oil technology circuit breakers. As described in AMS 10-54 Circuit Breakers, bulk-oil circuit breakers have proven expensive to maintain in comparison with more modern technologies. In addition, explosive failures of bulk oil circuit breakers have occurred in the past, resulting in plant damage and fire ignition.

Due to the large volume of insulating oil within the tanks and the high voltage bushings, failures could potentially cause collateral damage to adjacent high voltage plant, cables, secondary systems and onsite personnel. Spillage of oil also poses environmental hazards and clean-up costs as bulk oil circuit breakers are not positioned within a bunded area.

### 7.1.3 Current Transformers

As described in AMS 10-64 Instrument Transformers, several explosive failures[6] have confirmed that deteriorated single-phase, porcelain clad, oil insulated current transformers present an unacceptable risk. This risk includes supply outages, collateral plant damage, environment damage and possible injury to personnel. A progressive replacement with toroidal current transformers incorporated within plant such as dead tank circuit breakers is part of AusNet Services' asset management strategy to address these risks.

There are six [C-I-C] current transformers in the TSTS 66 kV switchyard that have been assessed as being in a poor condition.

4 X417 220 kV Transformer Bushing Replacement – Stage 1 at Ballarat Terminal Station, Ringwood Terminal Station and West Melbourne Terminal Station, completed in 2007.

5 X837 220 kV Transformer Bushing Replacement – Stage 2 at West Melbourne Terminal Station, Richmond Terminal Station, Ballarat Terminal Station, Geelong Terminal Station, Shepparton Terminal Station and Morwell Power Station, target completion in 2014.

6 Moorabool Terminal Station 2002 & 2005, Jeeralang Terminal Station 2003, Ballarat Terminal Station 2006 and Terang Terminal Station 2006.

## 7.2 Safety, Plant Collateral Damage and Environmental Risk Cost

The Electricity Safety Act requires AusNet Services to design, construct, operate, maintain and decommission its supply network to minimize hazards and risks, so far as is practicable, to the safety of any person arising from the supply network.

In practice this means safety risk should be proactively managed until the cost becomes disproportionate to the benefits. With respect to the management of safety risks that may cause a single fatality amongst a crew of workers; application of the principle of "as low as reasonably practicable" indicates costs in excess of $ [C-I-C] may be disproportionate.

The following assumptions were used to calculate the monetised safety, plant collateral damage and environmental hazards presented by the plant described in Section 7.1; consistent with the methodology described in AMS 10-24 Victorian Electricity Transmission Network – Asset Renewal Planning Guideline:

- An explosive failure or oil fire could injure or kill workers on site with an economic consequence cost of $ [C-I-C];
- Plant that contains large volumes of oil poses an environmental risk with an average consequence cost of $30k per event;
- Transformer with oil that contains poly-chlorinated biphenyls (PCB) poses an environmental risk with an average consequence cost of $100k per event;
- Plant collateral damage, including consequent supply outages, is on average $1.0 M per event.

The likelihood of the above hazards occurring at TSTS have been calculated from the major failure rates in the circuit breaker, current transformer and power transformer reliability centred maintenance (RCM) models and the CIGRE research into the probability of explosion and fire associated with major plant failures[7].

Figure 4 shows the expected safety, plant collateral damage and environmental risk cost at TSTS based on the following risks:

- Health and safety risk due to an instrument transformer, power transformer bushing or circuit breaker explosive failure;
- Environmental risk presented by insulating oil spillage;
- Collateral damage to adjacent plant due to catastrophic failure of plant.

7 Cigre Final Report of the 2004 – 2007 International Enquiry on Reliability of High Voltage Equipment.

[C-I-C]

Figure 4 – Expected Annual Safety, Plant Collateral Damage and Environmental Risk Cost

## 7.3 Reliability and Security of Supply Risk

### 7.3.1 66 kV Switchyard

A failure of the number 1 – 2 66 kV bus tie circuit breaker or a simultaneous major failure of two 66 kV feeder circuit breakers supplying the same 66 kV loop present a supply risk. The monetised supply risk for such asset failures have been calculated and included in the switching supply risk presented in Figure 5.

### 7.3.2 Transformers

A prolonged outage of one or two transformers at TSTS present a significant risk to electricity consumers. Figure 5 illustrates the growing N-1 and N-2 transformer supply risk.

### 7.3.3 Expected Supply Risk

Figure 5 shows the expected supply risk cost associated with 66 kV switchgear failures as well as 220/66 kV transformer failures (N-1 and N-2) at TSTS.

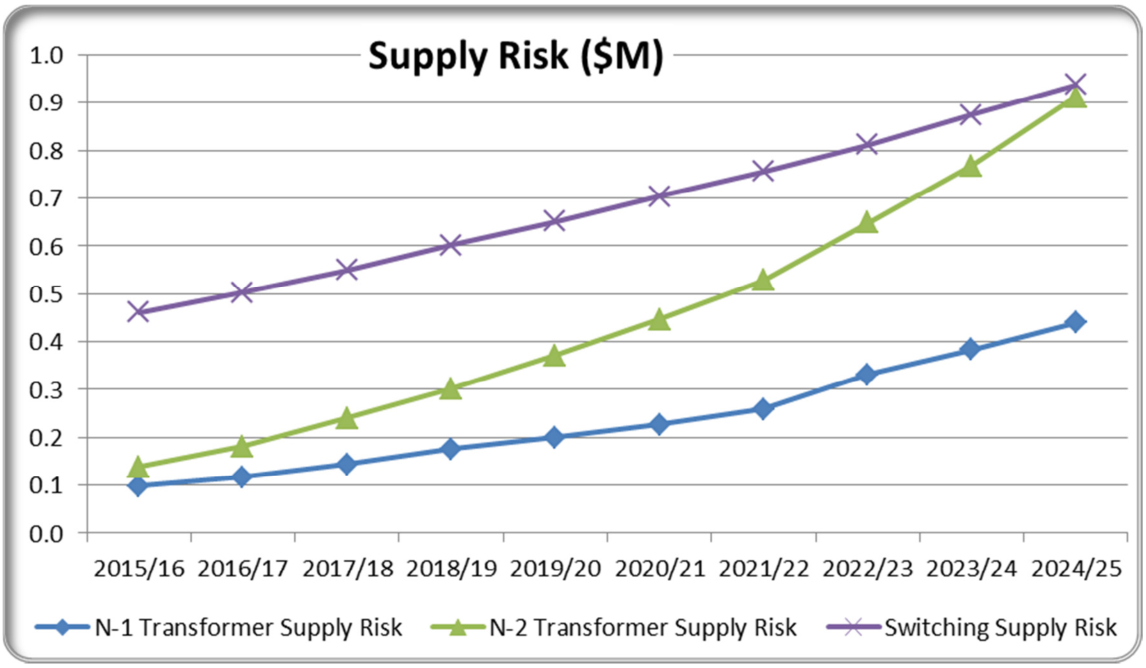


Figure 5 – Expected Supply Risk Cost for Transformer and 66 kV Switchgear Failures

## 7.4 Baseline Risk

The baseline risk[8] for TSTS is illustrated in Figure 6. The monetised baseline risk includes safety, environmental, collateral plant damage and security of supply risks involved with both major transformer failures resulting in extended transformer outages and initial plant failures. It presents the probability weighted risk at TSTS for the key risk components as calculated in the preceding sections 7.2, 7.3 and 7.4.

8 For details of the calculation of the baseline risk refer to the excel economic model of the SVTS Redevelopment.

[C-I-C]

Figure 6 – Baseline Risk

The baseline risk in Figure 6 is the probability weighted risk cost at TSTS of low probability, but high consequence events. It does not represent the actual societal cost of a fatality or injury, or loss of supply event. The societal cost of explosive plant failures that could injure or kill workers on site and/or critical plant outages that could result in a loss of supply from TSTS are much higher than the probability weighted monetised risk presented in Figure 6. It is estimated at $ [C-I-C] for a fatality, $3 M for a major transformer failure and $10 M for a circuit breaker failure. The high societal cost of plant failures, including explosive failures, suggests that options such as "Do nothing" or "Run to Failure" are not prudent asset management strategies for the asset failure risks at TSTS.

The safety and asset failure risk is forecast to progressively increase over time, predominantly due to the deteriorating condition of the transformers and switchgear. The societal cost due to plant failures at TSTS is also expected to increase as demand increases. Table 6 illustrates that significant capital investments may be economic to address the increasing base line risk at TSTS.

| YEAR | 2015/16 | 2016/17 | 2017/18 | 2018/19 | 2019/20 | 2020/21 | 2021/22 | 2022/23 | 2023/24 | 2024/25 |
|---|---|---|---|---|---|---|---|---|---|---|
| Annual Risk Cost ($) | 1.5 | 1.7 | 1.9 | 2.1 | 2.4 | 2.6 | 2.9 | 3.2 | 3.5 | 3.9 |
| Present Value Risk Cost at 7.5% Discount Rate ($M) | 19.5 | 21.7 | 24.4 | 27.3 | 30.2 | 33.3 | 36.6 | 41.0 | 45.3 | 50.0 |

Table 6 – Societal Risk

# 8 Options to Address Risks

The following options have been assessed to address the increasing community risk at TSTS:

- Business as usual. This option is included in the option analysis to define the baseline risk and to quantify the potential benefits of options that address the baseline risk
- Non network option of embedded generation and/or demand side response
- Run to failure and replace assets upon failure
- Integrated redevelopment with Air Insulated Switchgear (AIS) or Gas Insulated Switchgear (GIS)
- Staged redevelopment

# 9 Evaluation of Options

An economic cost-benefit assessment is used to assess and rank the economic efficiency of the non-network and network options listed in Section 8. The option analysis considers key aspects like operating cost versus capital cost trade-offs, security of supply risk during the construction phase of the project, economic merits of an integrated versus staged replacement and the future augmentation plans for TSTS.

A "Business as usual" option (Option 1) has been included in the option analysis to present the baseline risk. It illustrates whether deferment of asset replacement presents an economical option or whether the risk has reached a level that needs to be addressed during the 2017 to 2022 regulatory control period. Option 2 assesses the technical and economic merits of non-network options such as embedded generation and demand side management. Option 3 is a reactive asset replacement option. Options 4, 5, 6, and 7 involve proactive replacement of deteriorated and failure prone equipment based on the assessed risk of an asset failure.

The economic analysis allows comparison of the economic cost and benefits of each option to rank the options and to determine the economic timing of the preferred option. It quantifies the capital, operation and maintenance, and risk cost for each option. The risk cost includes safety, security of supply, environmental and collateral damage risks at TSTS. The robustness of the economic evaluation is tested for three discount rates, a sensitivity analysis of the forecast plant failure rates, different demand growth scenarios and different VCR rates.

Each of the identified options for TSTS is evaluated based on the incremental benefits it delivers in the following areas:

- Reduction in health and safety risk due to plant explosive failures;
- Reduction in supply risk due to unplanned outages;
- Reduction in environmental risk due to insulating oil spillage;
- Reduction in collateral plant damage risk due to explosive plant failures;
- Reduction in operation and maintenance cost, including network losses.

## 9.1 Option 1: Business as Usual

The baseline risk at TSTS, as shown in Figure 6 and Table 6, defines the economic cost for the "Business as Usual" option for the period until 2024/25. It shows that the annual risk cost increases from \$1.5 M to \$3.9 M over the period from 2015/16 to 2024/25. The Present Value of the risk cost, assuming a flat risk profile after 2024/25, is more than \$50 M[9]. This suggests that a "Business as Usual" approach would not be an economical option or a prudent management strategy for the assets at TSTS.

9 This is a conservative assumption as the risk cost is more likely to increase as a result of deteriorating plant condition and consequent failure rates, and demand growth.

The progressive reduction in reliability of supply and increase in safety risk is inconsistent with AusNet Services' obligations under the National Electricity Rules. Recurring asset failures is furthermore inconsistent with the requirements of the Electricity Safety Act and AusNet Services' accepted Electricity Safety Management Scheme.

This option is used in the economic evaluation as a reference to measure the economic benefits of options that mitigate the identified risks at TSTS and to ascertain the economical time[10] for a particular option to proceed.

## 9.2 Option 2: Non network options of embedded generation and/or demand side response

TSTS does not have any N-1 energy at risk under 50% POE conditions based on the current demand forecast for the planning period until 2024/25 and only a small amount of energy at risk on extremely warm days and summer 10% POE conditions. The economic benefits of non-network options are hence limited over the planning period and insufficient to warrant further analysis of this option based on typical costs for non-network options. Non network options cannot address the safety risk or meet the full supply requirements at TSTS.

## 9.3 Option 3: Run to failure

This option involves replacing assets upon failure, which poses a significant risk to the community. The community costs that would result from applying an asset management strategy to only replace an asset after the asset has failed is as follows:

- $2 M for a major failure of a 220/66 kV transformer.
- $10 M for a circuit breaker failure.

Some of the plant (transformer bushings, bulk oil 66 kV circuit breakers and instrument transformers) at TSTS also present a safety risk should they fail explosively. This risk cannot be managed with a "run to failure" strategy as it would involve workers replacing failed equipment in a switchyard containing other equipment known to be in a deteriorated condition with a potentially hazardous mode of failure. This type of safety risk is valued at $ [C-I-C] as a person/s could be injured or killed following an explosive failure.

Unplanned replacement of assets after a failure occurred is furthermore an inefficient asset replacement strategy for terminal stations due to the significant higher cost (project mobilisation and demobilisation) of emergency replacements.

Recurring unplanned outages associated with a series of asset failures is inconsistent with the requirements of the Electricity Safety Act, AusNet Services' accepted Electricity Safety Management Scheme and the National Electricity Rules. This option is hence only used for modelling purposes.

## 9.4 Option 4: Integrated Replacement with AIS

This option involves replacement of the B2 220/66 kV transformer, 66 kV switchgear and station services transformers in a single integrated project. This option is estimated to cost $34.2 M, delivers significant benefits and addresses most of the risks.

## 9.5 Option 5: Staged Replacement – Circuit Breakers

This option assesses the economic feasibility of a staged or selective rather than integrated replacement of the deteriorated assets at TSTS. The first stage replaces the condition C4 66 kV switchgear. The remainder of the deteriorated plant are replaced in a second stage, five years after completion of the first stage.

This option allows deferral of some asset replacements and is estimated to cost $20.1 M. It delivers significant benefits by addressing many of the risks.

10 "Do Nothing" is the default option until the year when the annual benefits (reduction in risk cost and operating cost) of the most economical option exceed the annual cost.

## 9.6 Option 6: Staged Replacement – Transformer

This option assesses the economic feasibility of a staged or selective rather than integrated replacement of the deteriorated assets at TSTS. The first stage replaces the B2 Transformer and station service transformers, followed by a second stage that replaces the 66 kV switchgear.

This option allows deferral of some asset replacements and is estimated to cost $18.7 M. It only address some of the risks.

## 9.7 Option 7: Brownfield GIS Redevelopment

This option is similar to Option 4, however the existing 66 kV air insulated switchgear (AIS) is replaced with compact gas insulated switchgear (GIS) within a building. Some of the existing rack structures and line termination structures remain, yet many of the overhead connections and feeder exits will be placed underground in this option.

This option assumes that planning permit requirements dictate the need for 66 kV GIS at TSTS at a much higher capital cost ($85.5 M) compared with Option 4. It is not expected that GIS equipment within a building will be a requirement of a planning permit. It, however, remains a possibility and may trigger contingency expenditures.

## 9.8 PV Analysis

The present value cost (taking into account the total project capital cost, supply risk cost, operation and maintenance cost, safety risk cost, environment cost and plant collateral damage risk costs) is calculated for all credible options and is summarised in Table 7. This allows for the options to be ranked based on their economic merits. A real discount rate of 7.5% is used for the base case.

| Options Title | Assessment of Options | Capital Cost[11] | PV Cost (7.5% DCR)[12] |
|---|---|---|---|
| 1. Business as usual | The baseline risk rises quickly, suggesting that a “Business as usual” approach is not sustainable. | | More than $50 M |
| 2. Non-Network Option | The low levels of energy at risk suggest that this option is uneconomic. | | Uneconomic |
| 3. Run to failure | This option is inconsistent with AusNet Services’ accepted ESMS, the Electricity Safety Act and AusNet Services’ obligations under the NER. | | |
| 4. Integrated Replacement | Address all the identified risks in a single efficient project. | $34.2 M | $34.2 M |
| 5. Staged Replacement – Circuit Breakers | Addresses most of the risks. | $20.1 M | $35 M |
| 6. Staged Replacement – Transformers | Addresses a limited number of risks. | $18.7 M | $39.8 M |
| 7. GIS Redevelopment | High capital cost. Fully address all risks. | $85.5 M | $67.5 M |

Table 7 – Economic Assessment of Options – Base case assumptions

11 Total project cost expressed in real 2015 dollars and includes project overheads and finance charges.

12 Present value cost expressed in real 2015 dollars at a 7.5% discount rate.

The robustness of the economic assessment is tested for different discount rates[13], VCR rates (low case at 0.75 x base case and high case at 1.25 x base case), asset failure rates (low case at 0.75 x base case failure rate and high case at 1.25 x base case failure rate) and demand growth rates (plus and minus 15% of the base case forecast) as shown in Table 8 below.

| | Discount Rate | | |
|---|---|---|---|
| | 6.0% | 7.5% | 9.0% |
| Option 1: Business as Usual | $64.933 | $57.537 | $51.137 |
| Option 4: Integrated Replacement | $36.915 | $34.259 | $31.843 |
| Option 5: Staged Replacement - Circuit Breakers | $38.417 | $35.066 | $32.093 |
| Option 6: Staged Replacement - Transformer | $43.808 | $39.824 | $36.299 |
| Option 7: GIS | $73.109 | $67.526 | $62.456 |
| Economic Option | Option 4 | Option 4 | Option 4 |

| | VCR Rate | | |
|---|---|---|---|
| | Low | Base | High |
| Option 1: Business as Usual | $50.242 | $57.537 | $64.831 |
| Option 4: Integrated Replacement | $33.009 | $34.259 | $35.510 |
| Option 5: Staged Replacement - Circuit Breakers | $33.335 | $35.066 | $36.798 |
| Option 6: Staged Replacement - Transformer | $37.739 | $39.824 | $41.908 |
| Option 7: GIS | $66.275 | $67.526 | $68.776 |
| Economic Option | Option 4 | Option 4 | Option 4 |

| | Asset Failure Rate | | |
|---|---|---|---|
| | Low | Base | High |
| Option 1: Business as Usual | $42.446 | $57.537 | $74.089 |
| Option 4: Integrated Replacement | $31.514 | $34.259 | $37.202 |
| Option 5: Staged Replacement - Circuit Breakers | $31.745 | $35.066 | $38.750 |
| Option 6: Staged Replacement - Transformer | $35.288 | $39.824 | $44.700 |
| Option 7: GIS | $64.778 | $67.526 | $70.472 |
| Economic Option | Option 4 | Option 4 | Option 4 |

| | Demand Growth | | |
|---|---|---|---|
| | Low | Base | High |
| Option 1: Business as Usual | $43.853 | $57.537 | $92.417 |
| Option 4: Integrated Replacement | $31.977 | $34.259 | $40.334 |
| Option 5: Staged Replacement - Circuit Breakers | $31.538 | $35.066 | $44.597 |
| Option 6: Staged Replacement - Transformer | $36.284 | $39.824 | $48.868 |
| Option 7: GIS | $65.244 | $67.526 | $73.601 |
| Economic Option | Option 5 | Option 4 | Option 4 |

Table 8 – Economic Assessment of Options – Sensitivity Study

## 9.9 Economic Option and Economical Timing

The integrated replacement option (Option 4) is the most economic option to address the plant failure risks at TSTS as it has the lowest PV cost for all the scenarios except the low demand growth scenario shown in Table 8.

13 AER Regulatory Investment Test for Transmission, June 2010. The present value calculations must use a commercial discount rate appropriate for the analysis of a private enterprise investment in the electricity sector. The discount rate used must be consistent with the cash flows being discounted. The lower boundary should be the regulated cost of capital, which is estimated at 6% (real and pre-tax).

The PV for Option 4 is also calculated for a series of different years to determine the economical timing for it to proceed, consistent with the RIT-T guidelines. This assessment concludes that the economic timing for project completion is before Summer 2021/22 where after the PV cost rise significantly.

| Project Economic Timing (PV Cost $M) | 2017/18 | 2018/19 | 2019/20 | 2020/21 | 2021/22 | 2022/23 |
|---|---|---|---|---|---|---|
| Project PV Cost | 34.78 | 34.38 | 34.24 | 34.26 | 34.41 | 34.71 |

Table 9 – Economic Timing

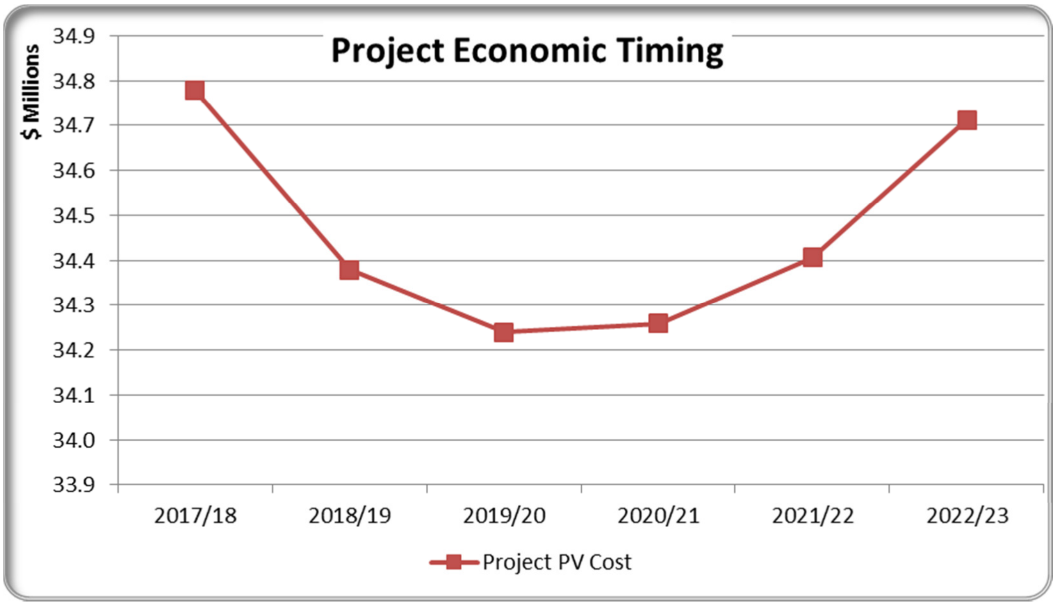


Figure 7 - Project Economic Timing

## 9.10 Sensitivity Studies

A sensitivity study[14] for higher (x 1.25) and lower (x 0.75) failure rates shows the economic timing of the redevelopment of TSTS may be as early as 2018/19 or as late as 2024/25. Due consideration of this sensitivity is important to avoid assets failure during the construction phase of the planned replacement project given the significant worker safety and community consequence.

14 The intersection of the annualized project cost plot and the incremental project benefits plot shows the project timing that delivers the optimum economic outcome.

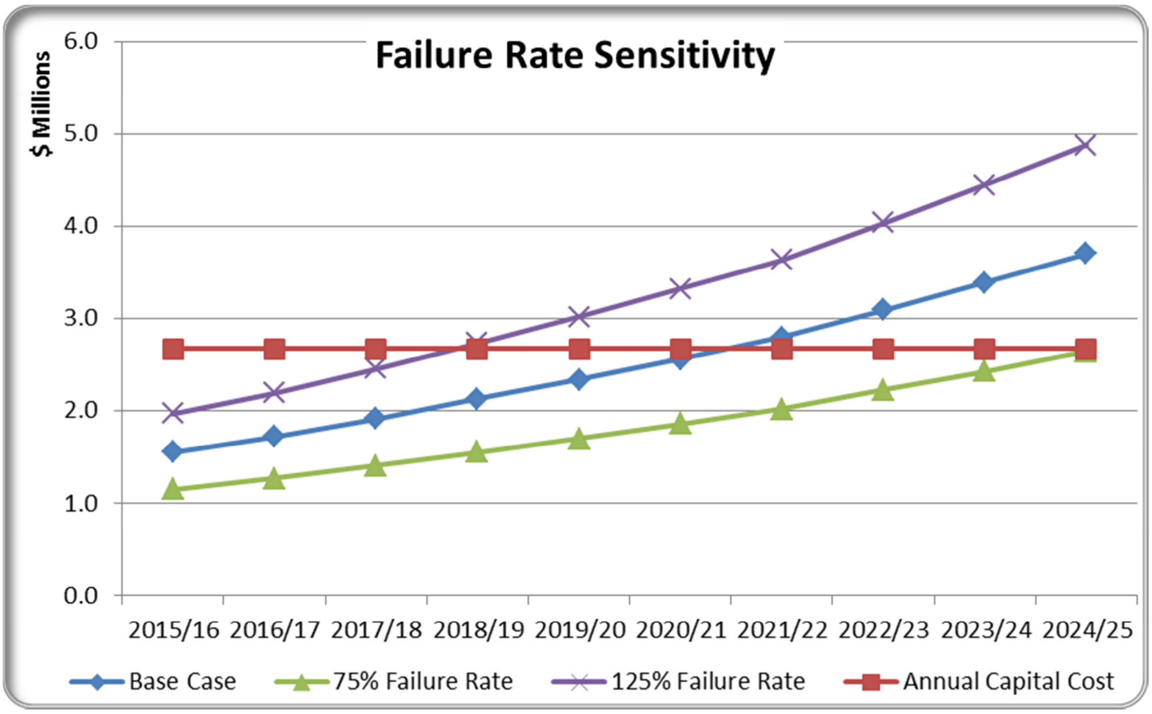


Figure 8 – Sensitivity Study – Plant failure rate higher or lower than expected

A sensitivity study for higher demand growth rates (15% above the base case) and lower demand growth rates (15% below the base case) shows that the project economic timing may be as early as 2017/18 or as late as 2023/24. Due consideration of this sensitivity is important to avoid un-necessary risk during the planned replacement project given the significant safety and community consequence.

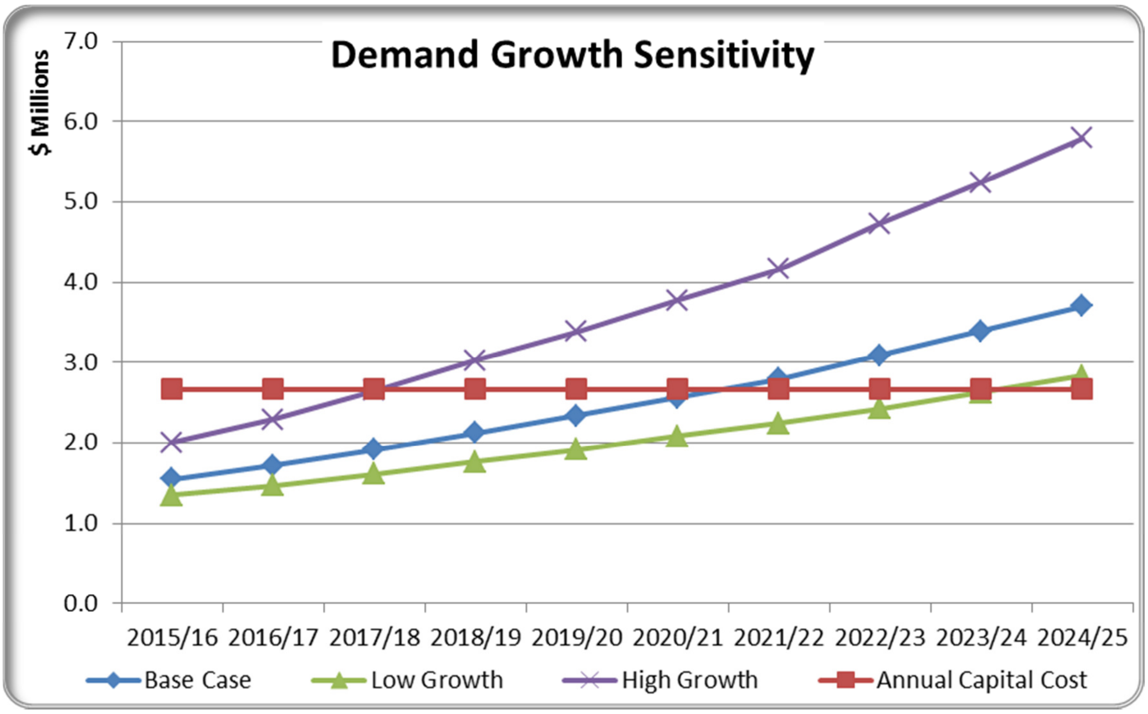


Figure 9 – Sensitivity Study – Demand growth higher or lower than expected

The economical timing of the TSTS redevelopment is also tested for different VCR rates (25% higher or lower than the base case) as shown in Figure 10. The sensitivity study shows that the project economic timing may be as early as 2019/20 or as late as 2022/23. Due consideration of this sensitivity is important to avoid un-necessary risk during the planned replacement project given the significant safety and community consequence.

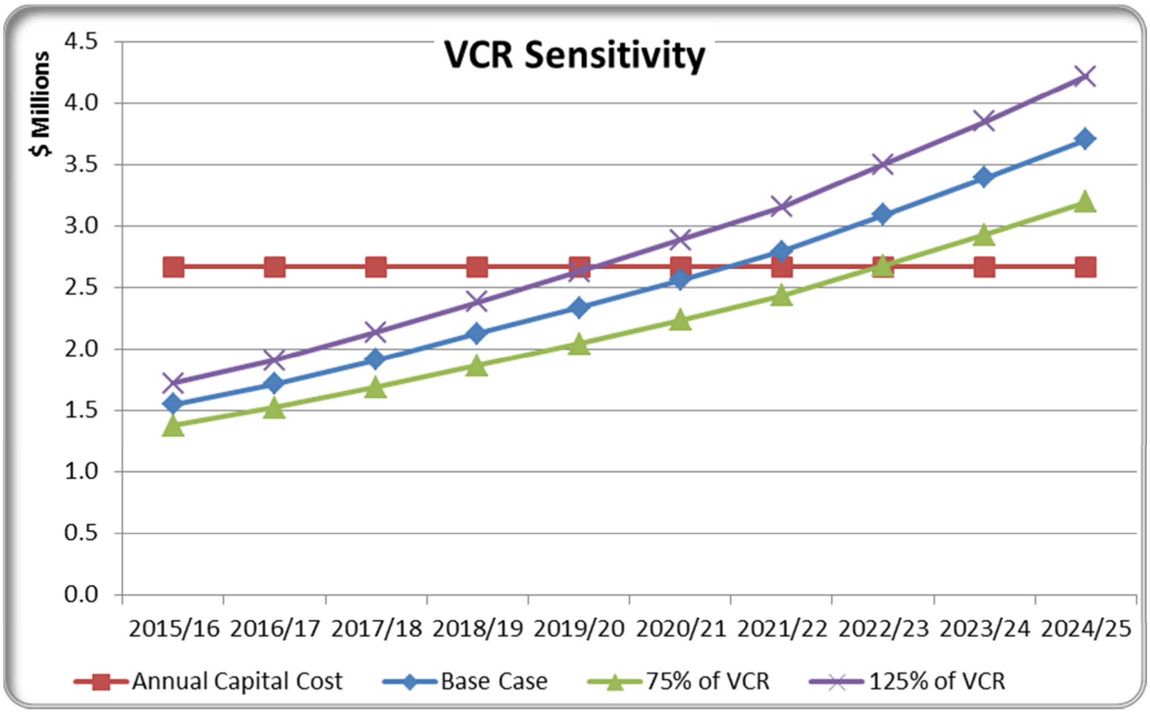


Figure 10 – Sensitivity Study – VCR Rates higher or lower than expected

Operational measures such as additional plant inspections and condition monitoring to manage the safety risk until planned replacements are completed is economical based on the safety risk assessment in Section 7.2.

# 10 Scope of Work

The high level scope of work for the preferred solution (Option 4) includes:

- Replacing the B2 transformer adjacent to the existing transformers to avoid increased supply risk during the replacement of the transformer.
- 220 kV Single switching for the existing B1 and B3 transformers
- Replacing all bus tie, transformer and C4 condition feeder 66 kV switchbays
- Installing new 66 kV bus voltage transformers
- Replacing the station service transformers
- Installing new duplicate transformer protection schemes including Circuit Breaker Management schemes for the 66 kV circuit breakers

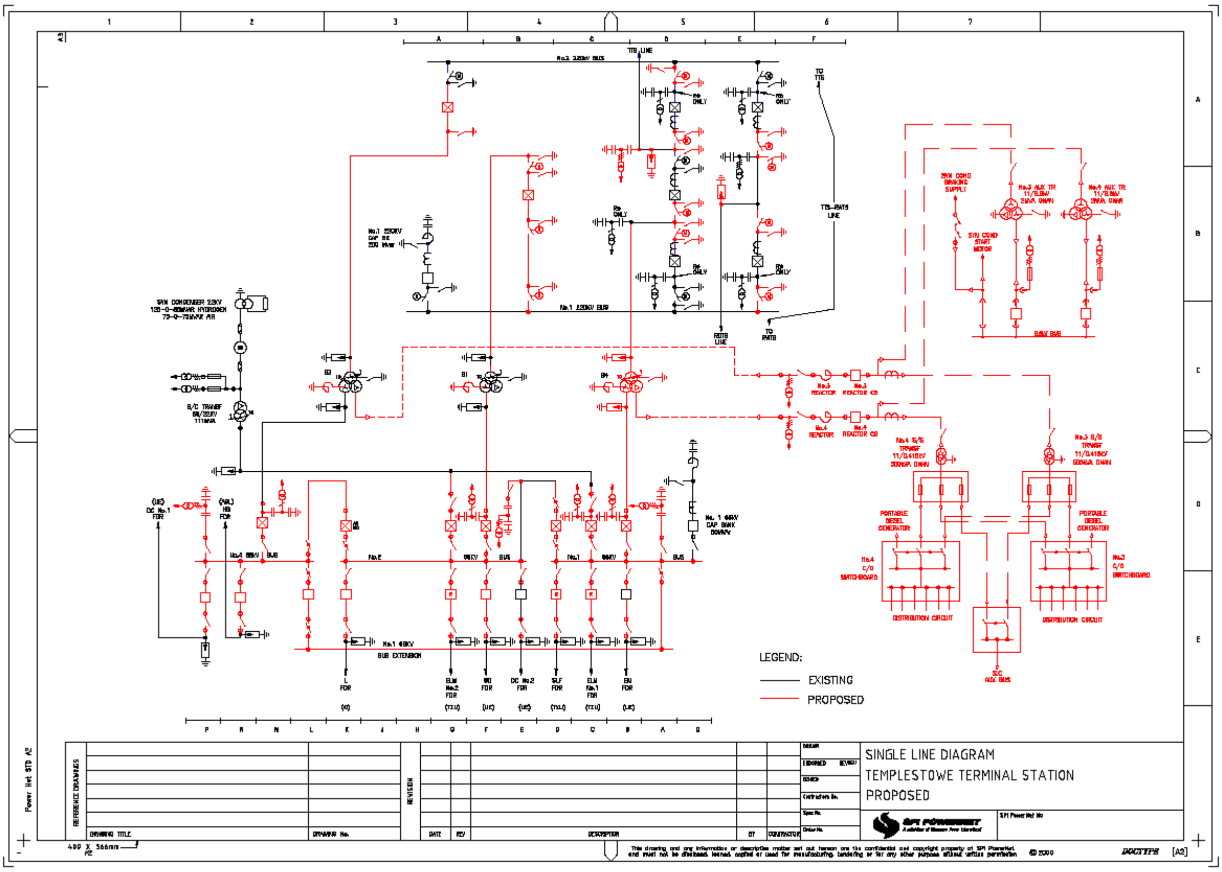


Figure 11: Proposed works at TSTS (Option 4)

## APPENDIX A: PLANNING ESTIMATE FOR PREFERRED OPTION: OPTION 4 - INTEGRATED REPLACEMENT

| |
|---|
| [C-I-C] |

*Note: The costs in the table above are expressed in 2015 real dollars.*