AusNet Transmission Group Pty Ltd

Transmission Revenue Review 2017-2022

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AMS – Electricity Transmission Network

Planning Report Project 285A

Fishermans Bend 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 Fishermans Bend Terminal Station (FBTS). 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 FBTS are 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, 220 kV circuit breaker bushings, 66 kV bulk oil circuit breakers or transformer bushings;
- Security of supply risks presented by a failure of the 220/66 kV transformers, 220 kV circuit breakers 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 FBTS 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
- Replacement with larger transformers;

The most economic option to address the emerging constraints at FBTS is an integrated replacement project that replaces all the deteriorating assets and that addresses all emerging risks. This option has the lowest present value cost ($34.8 M) and is consistent with the future development plans for FBTS. The economic timing for project completion is 2019/20 with an estimated total capital cost of $36.9 M ($31.9 M direct $2015).

2 Purpose

This planning report outlines asset condition, asset failure risks and network development plans relevant to FBTS 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 FBTS 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

FBTS is located near Melbourne's CBD and supplies the Docklands areas and an area south-west of the City of Melbourne bounded by the Yarra River in the north and west, St Kilda/Queen's Roads in the east and Hobsons Bay in the south via 66 kV feeders. The main supply areas include Docklands and Southbank of the Central Business District planning areas, Port Melbourne, Fisherman's Bend, Albert Park, Middle Park and St Kilda West.

FBTS is connected to the Western metropolitan 220 kV ring with two 220 kV transmission lines from West Melbourne Terminal Station (WMTS) and transmission lines to Brooklyn Terminal Station (BLTS) and New Port Power Station as shown in Figure 1, below. Both sets of 220 kV lines are arranged on double-circuit towers.

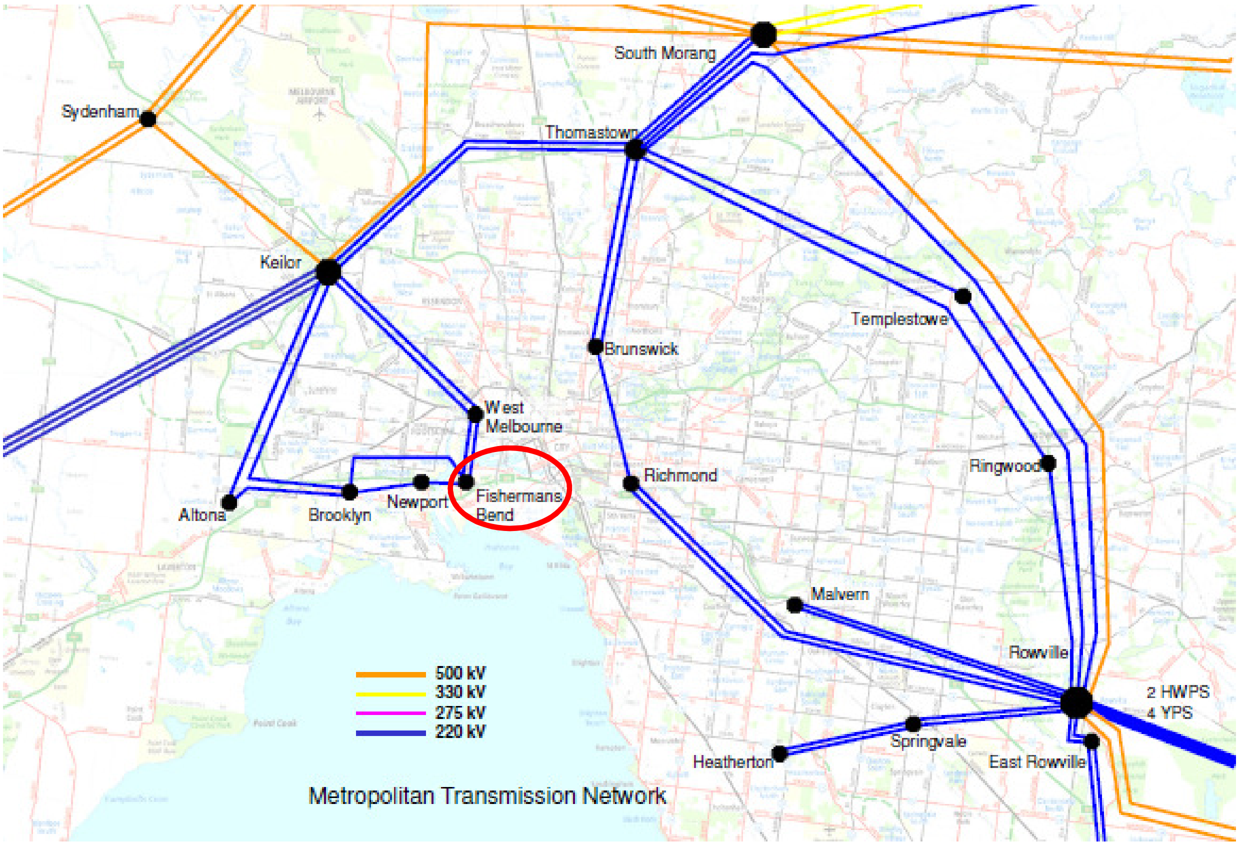

Figure 1 – Metropolitan Melbourne Transmission Network

Transformation at FBTS comprises of three 150 MVA 220/66 kV transformers that provide transmission connection services to CitiPower and Powercor.

A synchronous condenser (SCO) provides dynamic reactive support, but is being considered for retirement due to changing shared transmission network needs, high operation and maintenance cost and the condition of the SCO.

The 66 kV switchyard includes ten feeders, three buses and three bus-ties. Figure 2, below shows the present configuration at FBTS.

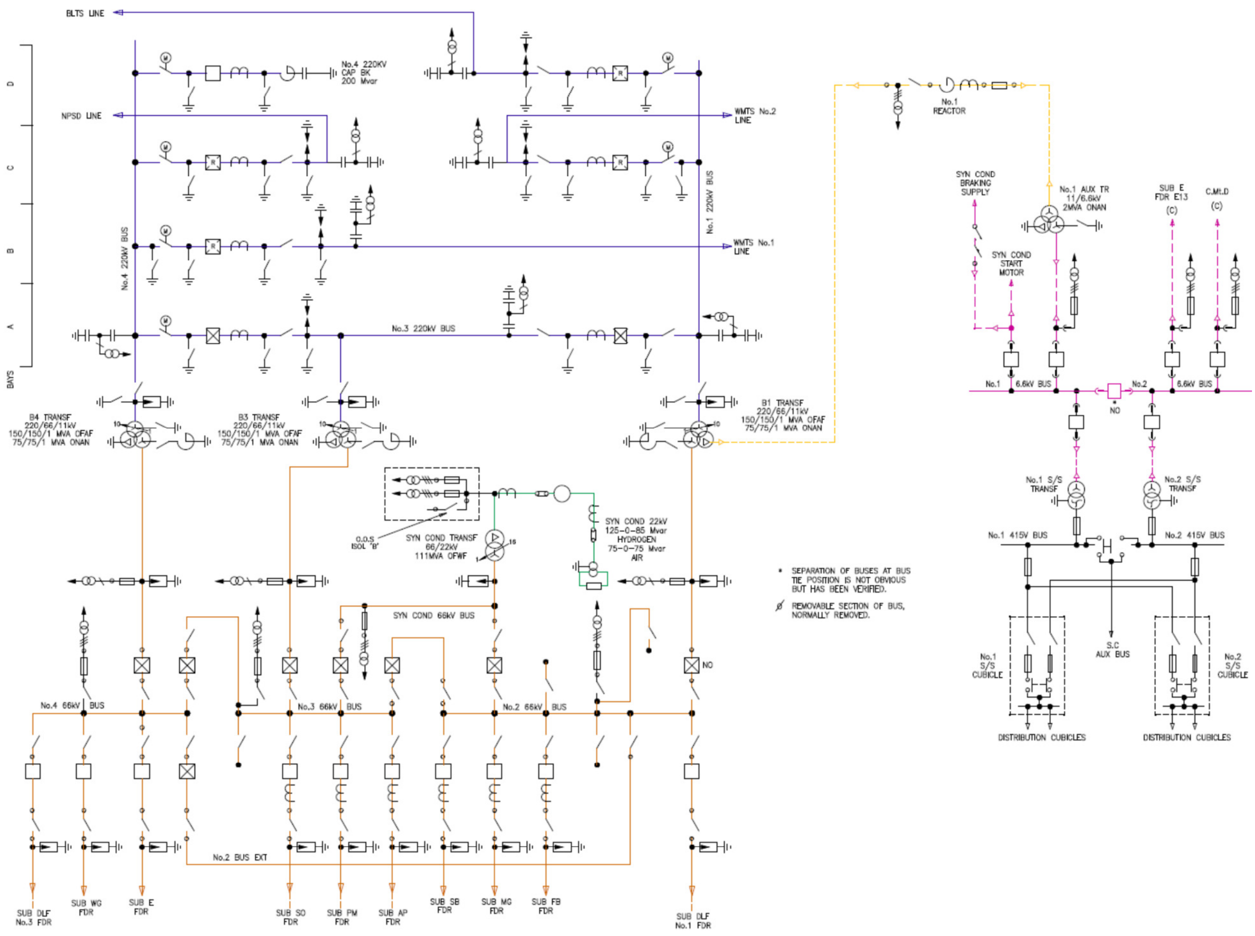

Figure 2 – Single Line Diagram of FBTS

Many of the primary and secondary assets installed at the time that FBTS 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.

An approved project, XC17, is replacing some critical assets, including one 220 kV circuit breaker, all 66 kV bus tie circuit breakers, all transformer 66 kV circuit breakers and one 66 kV feeder circuit breaker. Project XC17 is the first stage of a staged redevelopment of FBTS.

5 Planning Considerations

5.1 Planning Responsibilities

The augmentation responsibility for FBTS lays with the Australian Energy Market Operator (AEMO) for the shared transmission network and with the distributors, CitiPower and Powercor, for the transmission connection assets.

5.2 Demand Forecast

FBTS 66 kV is a summer peaking station and demand is forecast to grow over the planning period as a result of new developments planned in the Fishermans Bend precinct. 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 grow at an average annual rate of 3.0% and 2.8% for the Summer POE10 and POE50 forecasts respectively.

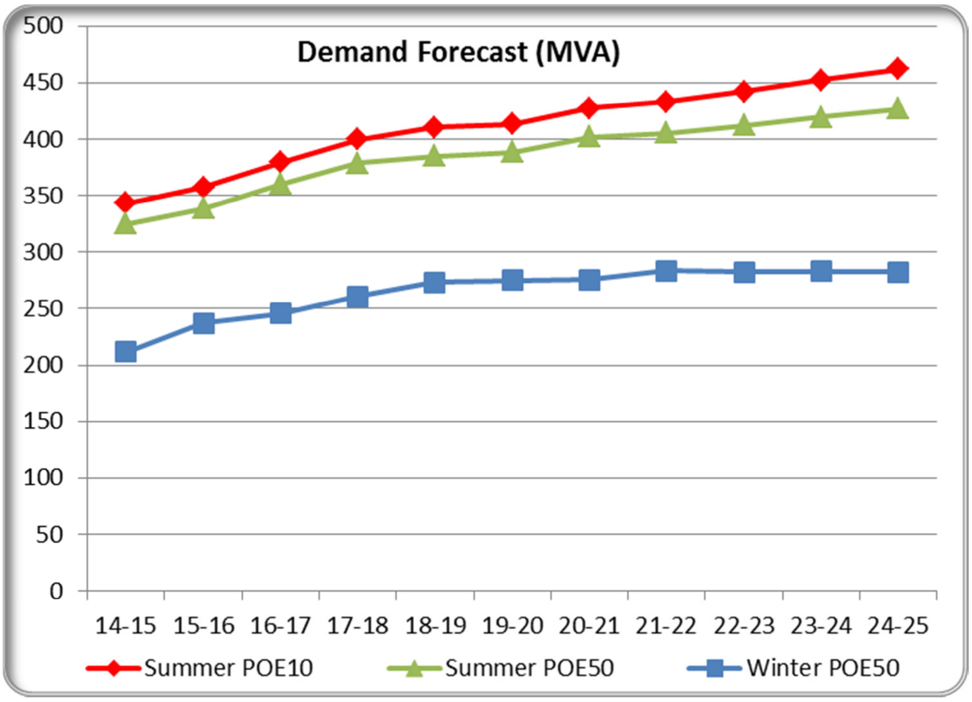

Figure 3 –Distribution Business demand Forecast for FBTS

AEMO has for the first time also prepared a connection point forecast for Victoria. AEMO's 2014 connection point demand forecast for FBTS shows lower growth (1.1% for Summer POE10 and 0.9% for Summer POE50) over the planning period as illustrated in Figure 4.

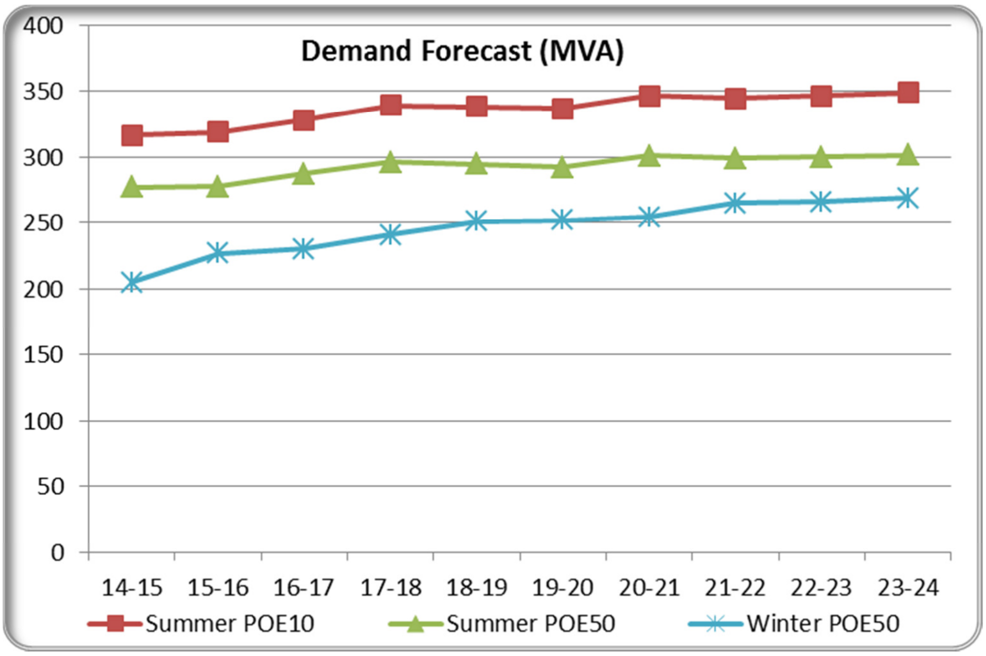

Figure 4: AEMO Demand Forecast for FBTS

The average of the two demand forecasts (AEMO and Distribution Business demand forecasts) is used for the base case in the economic evaluation of the replacement project proposed at FBTS.

5.3 Future Planning Requirements

Any significant asset replacements at FBTS 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 FBTS, which include the following:

- Five 225 MVA 220/66 kV transformers for the ultimate development plan and for an economic transition from 150 MVA 220/66 kV transformers to 225 MVA 220/66 kV transformers. The transition from 150 MVA transformers to 225 MVA transformers should not reduce the station N and N-1 capability due to unequal load sharing between the 225 MVA and 150 MVA transformers;
- Up to four new 220 kV lines or cables to be connected at FBTS with the understanding that more land would be required to achieve this ultimate development plan
- Six 66 kV busbars with four feeders and one capacitor bank per bus;

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 FBTS 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 FBTS has been assessed according to AMS 10-67 and is shown in Table 2.

DESCRIPTION	INSTALL YEAR	ASSET CONDITION	Core & Windings	Bushings	Oil	Tap Changer	Tank/Aux
B1 220/66KV TRANSFORMER	1971	C4	C3	C4	C4	C4	C4
B3 220/66KV TRANSFORMER	1989	C4	C4	C3	C3	C3	C3
B4 220/66KV TRANSFORMER	1971	C3	C3	C3	C3	C3	C2

Table 2 – Transformer Condition Score

The B1 transformer is an [C-I-C] transformer and it has major oil leaks with deterioration of the winding primary insulation system. The B3 transformer is a [C-I-C] transformer of similar design as the failed Thomastown (TTS) B1 transformer. A design defect has been identified for the TTS B1 and the FBTS B3 transformers and a major fault on the 66 kV network near FBTS is likely to result in a major failure of the FBTS B3 transformer. The B4 transformer is a [C-I-C] unit that has been assessed as C3 or "normal condition for age".

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.

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 3.6% to 5.5% over the planning period until 2022.

6.2 220 kV Circuit Breakers

There are seven 220 kV SF6 type circuit breakers at FBTS of which one circuit breaker (No.1-3 bus tie) will be replaced under Project XC17. All seven 220 kV circuit breakers are now older than 30 years and their condition scores are shown in Table 3.

CIRCUIT	INSTALL YEAR	MANUFACTURER	ASSET CONDITION
BLTS 220KV LINE CB AT FBTS	1981	DELLE ALSTHOM	C4
1-3 220KV BUS TIE CB AT FBTS	1982	ASEA	C4
NPSD 220KV LINE CB AT FBTS	1983	ASEA	C3
WMTS NO.2 220KV LINE CB AT FBTS	1983	ASEA	C3
WMTS NO.1 220KV LINE CB AT FBTS	1983	ASEA	C3
3-4 220KV BUS TIE CB AT FBTS	1983	ASEA	C3
NO.4 220KV CAPACITOR BANK CB AT FBTS	1997	SIEMENS	C2

Table 3 – 220 kV Circuit Breaker Condition Score

6.3 220 kV Current Transformers

There are three [C-I-C] 220 kV post-type current transformers installed at FBTS. As described in AMS 10-64[1], [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.

At least two [C-I-C] current transformers have failed in this manner on the Victorian transmission network over the last ten years[2]. [C-I-C] current transformers (all voltage levels) have been monitored closely since those failures to manage the safety risk they present. This frequent monitoring has successfully revealed accelerated deterioration and imminent failure and many units have been safely replaced as a result.

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. Further, ongoing DGA analysis continues to show a trend towards failure, demonstrating clearly that Tyree 330 kV, 275 kV and 220 kV current transformers represent some of our highest risk types. AusNet Services' asset management strategy is therefore to completely replace the remaining fleet.

Table 4 shows the asset condition of the 220 kV [C-I-C] current transformers at FBTS.

1 AMS 10-64 Instrument Transformers.

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

CIRCUIT	MANUFACTURER	INSTALL YEAR	ASSET CONDITION
NO.4 220KV CAPACITOR BANK CB CT R/PH AT FBTS	[C-I-C]	1997	C4
NO.4 220KV CAPACITOR BANK CB CT W/PH AT FBTS	[C-I-C]	1995	C4
NO.4 220KV CAPACITOR BANK CB CT B/PH AT FBTS	[C-I-C]	1995	C4

Table 4 – 220 kV Current Transformer Condition Score

6.4 66 kV Circuit Breakers

Most of the 66 kV circuit breakers at FBTS are bulk oil circuit breakers as indicated in Table 5. These bulk-oil circuit breakers are amongst the oldest circuit breakers installed in the network, ranging in service age from 50 to 42 years old. Asset Management Strategy AMS 10-106[3] provides a summary of the key issues of this type of bulk oil 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;
- Limited fault level capability requiring restrictive switching configurations;
- Maintenance intensive;
- Manufacturer no-longer provides technical support or spares;
- Insufficient oil bunding.

CIRCUIT	INSTALL YEAR	MANUFACTURER	TYPE	ASSET CONDITION
PM 66KV FDR CB AT FBTS	1982	[C-I-C]	SF6 LTCB	C5
2-3 66KV BUS TIE CB AT FBTS	1965	[C-I-C]	Bulk Oil	C4
SYN/COND TRANS NO.2 BUS 66KV CB AT FBTS	1967	[C-I-C]	Bulk Oil	C4
SYN/COND TRANS NO.3 BUS 66KV CB AT FBTS	1967	[C-I-C]	Bulk Oil	C4
B3 TRANS 66KV CB AT FBTS	1968	[C-I-C]	Bulk Oil	C4
3-4 66KV BUS TIE CB AT FBTS	1968	[C-I-C]	Bulk Oil	C4
DLF NO.1 66KV FDR CB AT FBTS	1971	[C-I-C]	Bulk Oil	C4
B4 TRANS 66KV CB AT FBTS	1971	[C-I-C]	Bulk Oil	C4
B1 TRANS 66KV CB AT FBTS	1971	[C-I-C]	Bulk Oil	C4
E 66KV FDR CB AT FBTS	1971	[C-I-C]	Bulk Oil	C4
WG 66KV FDR CB AT FBTS	1971	[C-I-C]	Bulk Oil	C4
2 EXTN-4 66KV BUS TIE CB AT FBTS	1971	[C-I-C]	Bulk Oil	C4
DLF NO.3 66KV FDR CB AT FBTS	1973	[C-I-C]	Bulk Oil	C4
FB 66KV FDR CB AT FBTS	1982	[C-I-C]	SF6 LTCB	C4
MG 66KV FDR CB AT FBTS	1982	[C-I-C]	SF6 LTCB	C4
SO 66KV FDR CB AT FBTS	1979	[C-I-C]	Min Oil	C4
AP 66KV FDR CB AT FBTS	1982	[C-I-C]	Min Oil	C3
SB 66KV FDR CB AT FBTS	1982	[C-I-C]	Min Oil	C3

Table 5 – 66 kV Circuit Breaker Condition Score

3 AMS 10-106 Circuit Breakers.

6.5 Secondary Systems

The protection and control systems at FBTS 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 FBTS and increase the associated operation and maintenance costs and risks.

7 Emerging Constraints

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

7.1 Safety and Environmental Hazards

7.1.1 Transformers

Transformers B1, B4 and the SCO transformer[4] at FBTS 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[5] (Stage 1) and Project X834[6] (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.

7.1.2 Circuit Breakers

Most of the 66 kV circuit breakers at FBTS 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[7] 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 three [C-I-C] current transformers in the FBTS 220 kV switchyard. It has been ascertained that some of these current transformers are exhibiting thermal and partial discharge issues and declining Dissolved Gas Analysis (DGA) test results.

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[4] It is planned to retire the SCO transformer following the decision from AEMO to retire the FBTS SCO.

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

6 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.

7 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 Million per event.

The likelihood of the above hazards occurring at FBTS 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[8].

Figure 5 shows the expected safety, plant collateral damage and environmental risk cost at FBTS 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.

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

[C-I-C]

Figure 5 – Expected Annual Safety, Plant Collateral Damage and Environmental Risk Cost

7.3 Reliability and Security of Supply Risk

7.3.1 220 kV Switchyard

A major failure of the No.3-4 220 kV bus tie circuit breaker could result in a short outage of two 220/66 kV transformers until the fault has been isolated. The monetised supply risk for this asset failure has been calculated and included in the switching supply risk presented in Figure 6.

7.3.2 66 kV Switchyard

After completion of Project XC17 most of the 66 kV switching supply risk at FBTS will be eliminated. A simultaneous major failure of two 66 kV feeder circuit breakers supplying the same 66 kV loop may still 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 6.

7.3.3 Transformers

A prolonged outage of one or two transformers at FBTS present a significant risk to electricity consumers. Figure 6 illustrates the growing N-1 and N-2 transformer supply risk.

7.3.4 Expected Supply Risk

Figure 6 shows the expected supply risk cost associated with 220 kV and 66 kV switchgear failures as well as 220/66 kV transformer failures (N-1 and N-2) at FBTS.

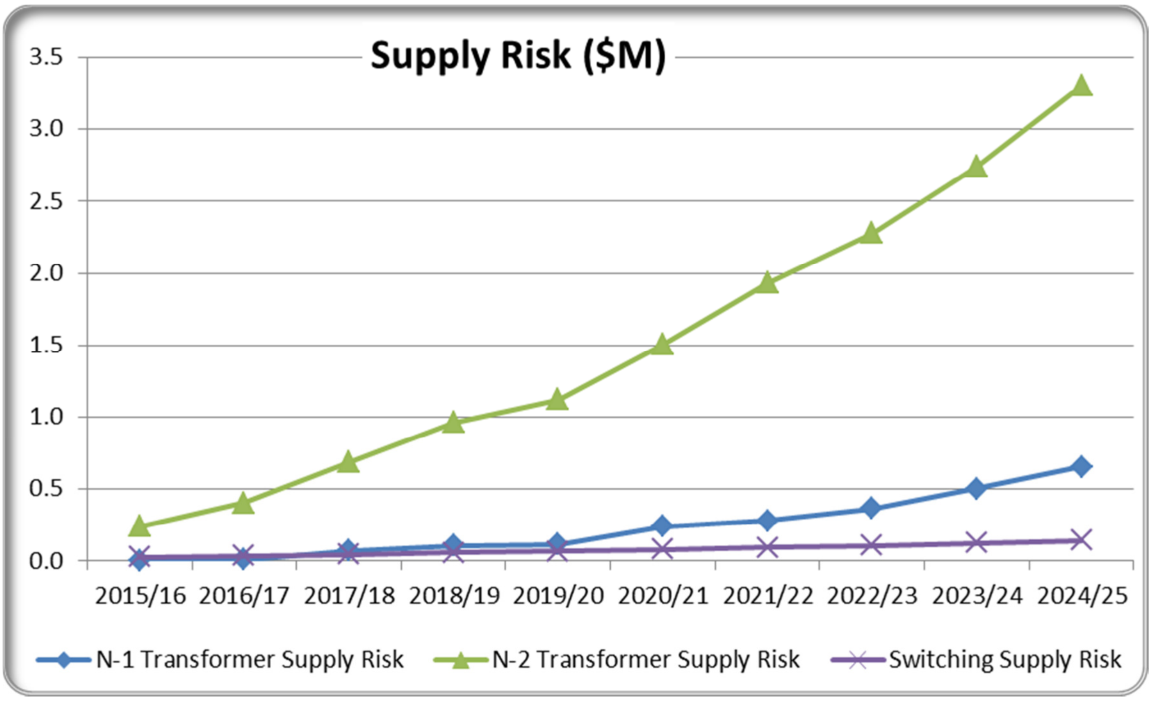

Figure 6 – Expected Supply Risk Cost for Transformer, and 220 kV and 66 kV Switchgear Failures

7.4 Baseline Risk

The baseline risk[9] for FBTS is illustrated in Figure 7. 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 FBTS for the key risk components as calculated in the preceding sections 7.2, 7.3 and 7.4.

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

[C-I-C]

Figure 7 – Baseline Risk

The baseline risk in Figure 7 is the probability weighted risk cost at FBTS 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 FBTS are much higher than the probability weighted monetised risk presented in Figure 7. It is estimated at [C-I-C] for a fatality, $2.6 M for a major transformer failure and $1.0 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 FBTS.

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 FBTS 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 FBTS.

YEAR	**2015/16**	**2016/17**	**2017/18**	**2018/19**	**2019/20**	**2020/21**	**2021/22**	**2022/23**	**2023/24**	**2024/25**
Annual Risk Cost ($)	1.1	1.3	1.7	2.1	2.4	3.0	3.5	4.0	4.7	5.6
Present Value Risk Cost at 7.5% Discount Rate ($M)	13.5	16.7	22.1	27.1	30.3	37.9	45.1	51.8	60.8	71.2

Table 6 – Societal Risk

8 Options to Address Risks

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

- 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)
- Staged redevelopment
- Replace with larger transformers

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 FBTS.

A "Business as usual" option (Option 1) has been included in the option analysis to presents 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 FBTS. 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 FBTS 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 FBTS, as shown in Figure 7 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 $13.5 M to $72.1 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 $72 M[10]. This suggests that a "Business as Usual" approach would not be an economical option or a prudent management strategy for the assets at FBTS.

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 FBTS and to ascertain the economical time[11] for a particular option to proceed.

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

FBTS does not have any N-1 energy at risk under 50% POE conditions based on the current demand forecast for the planning period until 2024/250 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 FBTS.

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:

- $2.6 M for a major failure of a 220/66 kV transformer.
- $1 M for a circuit breaker failure.

Some of the plant (transformer bushings, bulk oil 66 kV circuit breakers and instrument transformers) at FBTS 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 150 MVA Transformers

This option involves replacement of selected 220 kV and 66 kV assets with elevated failure risks and includes a reconfiguration of the 220 kV switchyard using air insulated switchgear in a single integrated project. The replacement of two of the existing three transformers uses the same size transformers, 150 MVA, as the most economic replacement option.

This option is estimated to cost $36.9 M, delivers significant benefits and addresses most of the risks.

10 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.

11 "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.

9.5 Option 5: Staged Replacement with 150 MVA Transformers

This option assesses the economic feasibility of a staged rather than integrated replacement of the deteriorated assets at FBTS. The first stage replaces the 220 kV switchgear (condition C5), one of the three 220/66 kV transformers and critical 66 kV switchgear such as the bus tie circuit breakers and transformer incomer circuit breakers. The remainder of the plant are replaced in a second stage, five years after completion of the first stage.

This option allows deferral of some asset replacements and Stage 1 is estimated to cost $26.8 M. It delivers significant benefits by addressing some of the risks.

9.6 Option 6: Integrated Replacement with 225 MVA Transformers

This option assesses the economic feasibility of an integrated replacement of the deteriorated assets at FBTS; utilising 225 MVA replacement transformers. This option is the same as Option 4 except that the existing 150 MVA 220/66 kV transformers are replaced with 225 MVA 220/66 kV transformers.

This option is estimated to cost $47.1 M and is the most expensive option. It address all of the risks and delivers significant benefits.

9.7 Option 7: Staged Replacement with 225 MVA Transformers

This option assesses the economic feasibility of a staged replacement of the deteriorated assets at FBTS; utilising 225 MVA replacement transformers. Stage 1 and Stage 2 of this option is the same as Option 5 except that the existing 150 MVA 220/66 kV transformers are replaced with 225 MVA 220/66 kV transformers.

This option allows deferral of some asset replacements and Stage 1 is estimated to cost $29.4 M. It only address some of the risks.

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[12] & Investment year	PV Cost (7.5% DCR)[13]
1. Business as usual	The baseline risk rises quickly, suggesting that a “Business as usual” approach is not sustainable.		More than $74 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.		

12 Total project cost expressed in real 2015 dollars.

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

Options Title	Assessment of Options	Capital Cost[12] & Investment year	PV Cost (7.5% DCR)[13]
4. Integrated Replacement 150 MVA Transformers	Address all the identified risks in a single efficient project	$36.9 M	$34.8 M
5. Staged Replacement – 150 MVA Transformers	Addresses most of the risks	$26.8 M	$37.9 M
6. Integrated Replacement 225 MVA Transformers	Address all the identified risks in a single efficient project. Highest capital cost	$47.1 M	$41.6 M
7. Staged Replacement – 225 MVA Transformers	Addresses most of the risks	$29.4 M	$38.9 M

Table 7 – Economic Assessment of Options – Base case assumptions

The robustness of the economic assessment is tested for different discount rates[14], asset failure rates (low case at 0.75 x base case failure rate and high case at 1.25 x base case failure rate), demand growth rates (plus and minus 15% of the base case forecast) and VCR rates (low case at 0.75 x base case and high case at 1.25 x base case) as shown in Table 8 below.

14 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).

	Discount Rate		
	6.0%	7.5%	9.0%
Option 1: Business as Usual	$83.755	$73.833	$65.264
Option 4: Integrated Replacement with 150 MVA Transformers	$37.150	$34.785	$32.609
Option 5: Staged Replacement - 150 MVA Transformers	$41.276	$37.940	$34.959
Option 6: Integrated Replacement with 225 MVA Transformers	$44.416	$41.576	$38.960
Option 7: Staged Replacement - 225 MVA Transformers	$42.281	$38.921	$35.913
Economic Option	Option 4	Option 4	Option 4

	VCR Rate		
	Low	Base	High
Option 1: Business as Usual	$61.963	$73.833	$85.702
Option 4: Integrated Replacement with 150 MVA Transformers	$33.935	$34.785	$35.634
Option 5: Staged Replacement - 150 MVA Transformers	$36.939	$37.940	$38.942
Option 6: Integrated Replacement with 225 MVA Transformers	$40.814	$41.576	$42.337
Option 7: Staged Replacement - 225 MVA Transformers	$38.129	$38.921	$39.714
Economic Option	Option 4	Option 4	Option 4

	Asset Failure Rate		
	Low	Base	High
Option 1: Business as Usual	$49.451	$73.833	$103.162
Option 4: Integrated Replacement with 150 MVA Transformers	$32.468	$34.785	$37.458
Option 5: Staged Replacement - 150 MVA Transformers	$35.276	$37.940	$40.968
Option 6: Integrated Replacement with 225 MVA Transformers	$39.364	$41.576	$44.132
Option 7: Staged Replacement - 225 MVA Transformers	$36.494	$38.921	$41.693
Economic Option	Option 4	Option 4	Option 4

	Demand Growth		
	Low	Base	High
Option 1: Business as Usual	$44.186	$73.833	$126.114
Option 4: Integrated Replacement with 150 MVA Transformers	$32.379	$34.785	$40.025
Option 5: Staged Replacement - 150 MVA Transformers	$34.996	$37.940	$44.673
Option 6: Integrated Replacement with 225 MVA Transformers	$39.465	$41.576	$45.947
Option 7: Staged Replacement - 225 MVA Transformers	$36.692	$38.921	$43.441
Economic Option	Option 4	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 FBTS as it has the lowest PV cost for all the scenarios shown in Table 8.

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 2019/20.

Project Economic Timing (PV Cost $M)	2017/18	2018/19	2019/20	2020/21	2021/22	2022/23
Option 4: Integrated Replacement with 150 MVA Transformers	35.38	34.98	34.78	34.96	35.46	36.19

Table 9 – Economic Timing

9.10 Sensitivity Studies

A sensitivity study[15] for higher (x 1.25) and lower (x 0.75) failure rates shows the economic timing of the redevelopment of FBTS may be as early as 2018/19 or as late as 2022/23. 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.

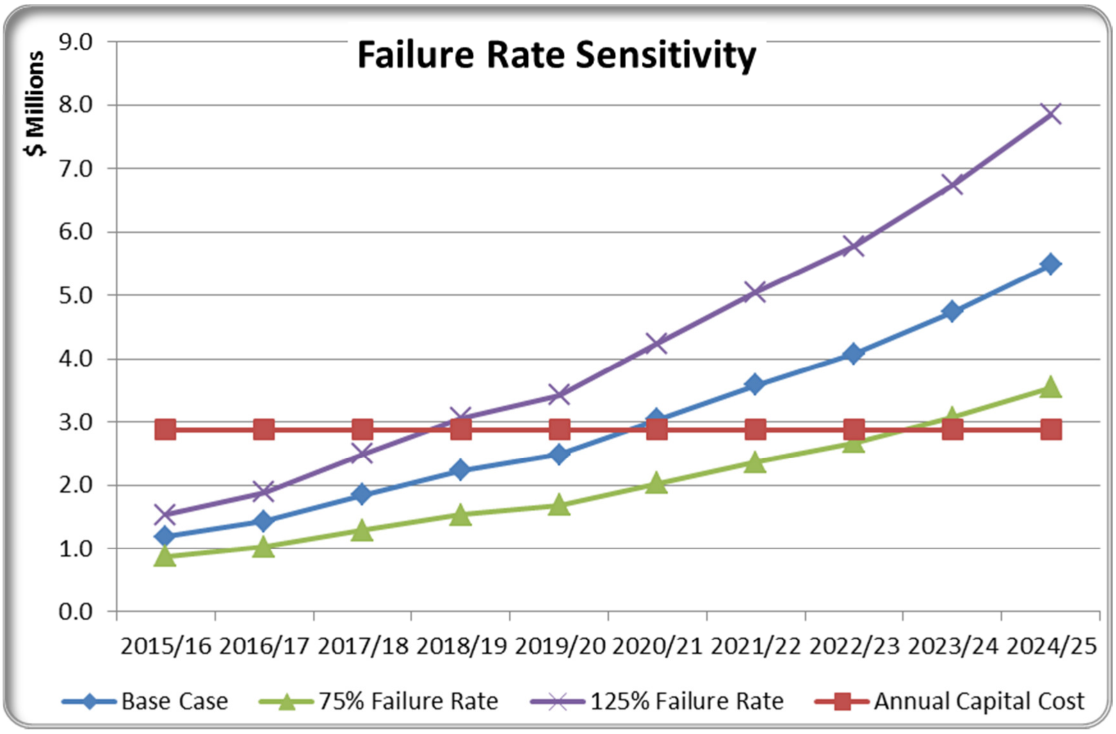

Figure 8 – Sensitivity Study – Plant failure rate higher or lower than expected

A sensitivity study for higher demand growth rates (10% above the base case) and lower demand growth rates (10% 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.

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

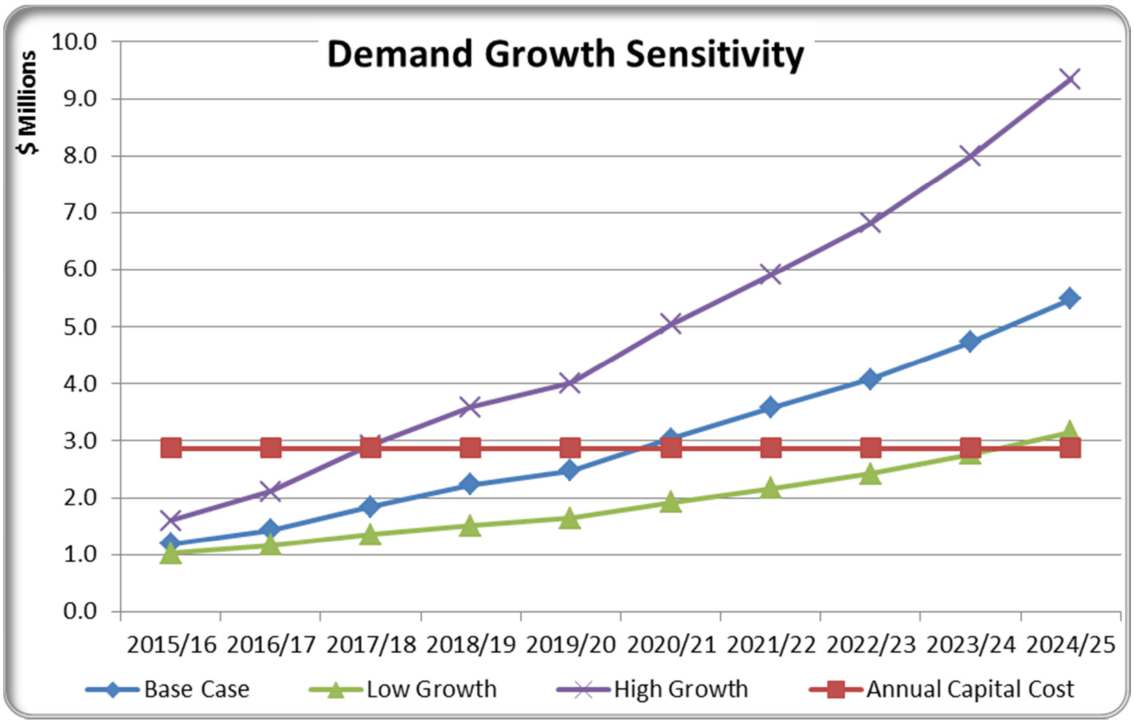

Figure 9 – Sensitivity Study – Demand growth higher or lower than expected

The economical timing of the FBTS 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 2021/22. Due consideration of this sensitivity is important to avoid unnecessary risk during the planned replacement project given the significant safety and community consequence.

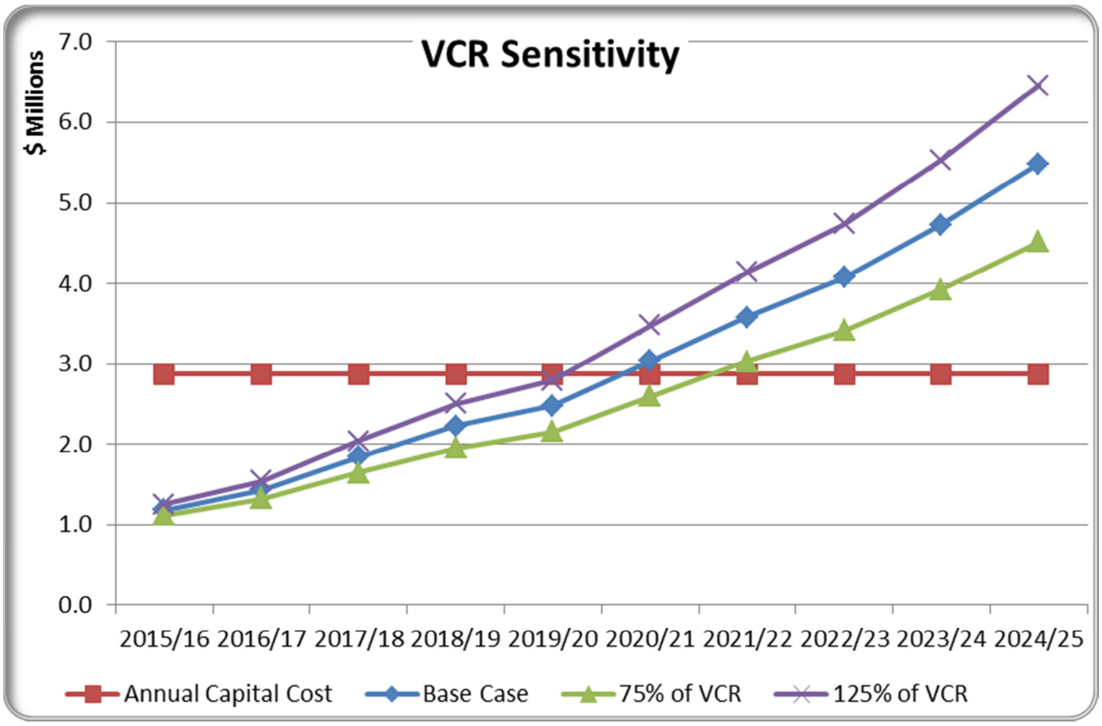

Figure 10 – Sensitivity Study – VCR Rates higher or lower than expected

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:

- Replacement of the B1 and B3 transformer with new 150MVA transformer in situ
- Building relevant circuit breakers to make two breaker and half circuit breaker bays and transferring the NPSD 220 kV line, BLTS 220 kV line and WMTS No.1 220 kV lines to replace the BLTS, two WMTS and 3-4 bus tie 220kV switchbays with shorter outage time
- Replacement of the No.4 220 kV capacitor banks CTs
- Replacement of seven 66kV feeder switch bays in situ.

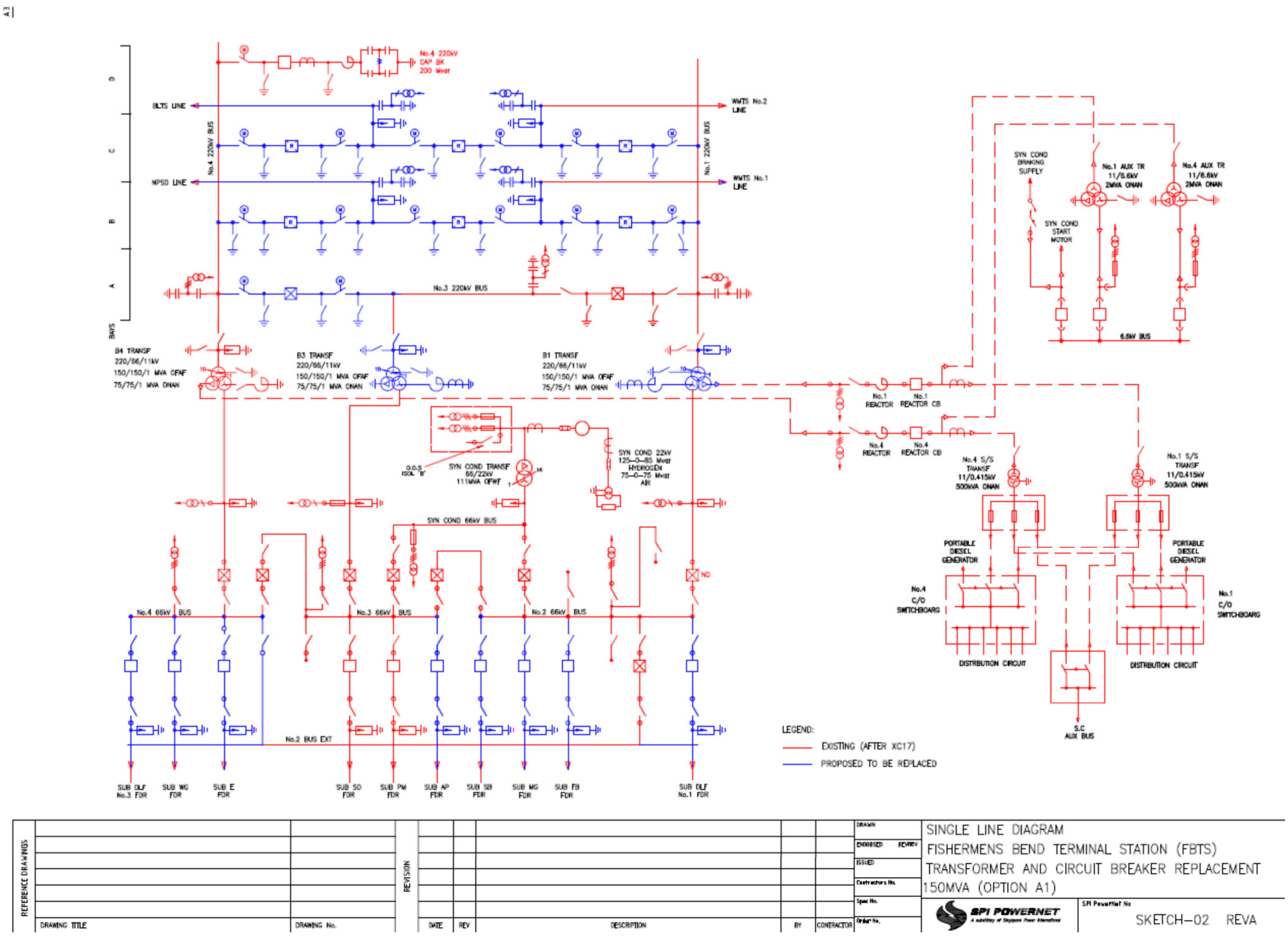

Figure 11: Proposed works at FBTS (Option 7)

The proposed switching configuration is in line with AEMO and CitiPower / Powercor's augmentation plan for FBTS and it is also consistent with the "breaker-and-half" switching standard for 220 kV and higher voltage transmission networks defined in AEMO's "Guidelines for Shared Transmission Connections in Victoria"[16].

16 Guidelines for Shared Transmission Connections in Victoria, published by AEMO.

APPENDIX A: PLANNING ESTIMATE FOR PREFERRED OPTION: OPTION 4 - INTEGRATED REPLACEMENT WITH 150 MVA TRANSFORMERS

[C-I-C]

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