Appendix 5.19: Zone substations – air insulated switchgear ASP

Regulatory proposal for the ACT electricity distribution network 2019-24
January 2018

Disclaimer: On 1 January 2018, the part of ActewAGL that looks after the electricity network changed its name to Evoenergy. This change has been brought about from a decision by the Australian Energy Regulator. Unless otherwise stated, ActewAGL Distribution branded documents provided with this regulatory proposal are Evoenergy documents.

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ASSET SPECIFIC PLAN

Zone Substations

Air Insulated Switchgear

Document Number: SM1102

Version Control

Date	Version	Description	Author	Reviewed
11/12/2014	1.0	2014-19 regulatory submission		
3/10/2017	1.1	New template with options analysis		
31/10/2017	2.0	Reviewed and updated options for forecast expenditure and modelling results		
7/12/2017	3.0	Document management system upgrade		
13/12/2017	4.0	Correct formatting		

Approval

Author	**Primary Assets Engineer**	13/12/2017 Name Date
Endorsed	**Primary Assets Manager**	13/12/2017 Name Date
Approved	**Branch Manager Asset & Network Performance**	13/12/2017 Name Date

Reference Documents

Document
National Electricity Rules
National Electricity Law
Utilities Act (ACT)
Electricity Distribution Asset Management Policy v7.0
Asset Management Strategy v2.16
Asset Management Objectives v1.3
Asset Management System Manual
PR5017 Recovery and disposal of reclaimed network assets
SM4606 Environmental PCB Management Plan
PJR - Decommission Fyshwick Zone Substation

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Glossary

Term	Definition
AAD	ActewAGL Distribution
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
ASP	Asset Specific Plan
BCT	Bushing Current Transformer
CAPEX	Capital Expenditure
CB	Circuit Breaker
CT	Current Transformer
DTCB	Dead Tank Circuit Breaker
FMEA	Failure Mode and Effects Analysis
HV	High Voltage
IED	Intelligent Electronic Device
IR	Insulation Resistance
kA	Kiloampere
kV	Kilovolt
LTCB	Live Tank Circuit Breaker
LV	Low Voltage
MVA	Mega Volt Ampere
NER	National Electricity Rules
NPC	Net Present Cost
OPEX	Operational Expenditure
PCB	Polychlorinated Bipheny
PJR	Project Justification Report
PoF	Probability of Failure
PoW	Program of Work
RPN	Risk Priority Number
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
STPIS	Service Target Performance Incentive Scheme
VT	Voltage Transformer

NOTE

All analysis has been undertaken using 2017/18 real dollars unless otherwise stated. Budgeted expenditure for CAPEX & OPEX excludes indirect costs.

Document Purpose

This document is an Asset Specific Plan (ASP). This ASP provides the business case for asset management strategy selection and specifies the activities and resources, responsibilities and timescales for implementation for this specific asset class. In conjunction with the other ASPs, it forms ActewAGL's Asset Management Plan, which describes the management of operational assets of the electricity distribution system.

Asset management options are assessed in the context of the asset class' current state, condition, performance, risks, life cycle costs, trends and external environment. A recommended asset strategy is presented with associated capital expenditure and operational expenditure forecasts, including a 10 year budget forecast, for consideration by ActewAGL management.

Detailed in this document are the systematic and coordinated activities and practices whereby ActewAGL manages the asset class in an optimal and sustainable manner for the purpose of achieving the organisational strategic plan.

Audience

This document is intended for internal use by ActewAGL management and staff. As part of legislative, regulatory and statutory compliance requirements, the audience of this document is extended to relevant staff of the ACT Technical Regulator and the Australian Energy Regulator.

Document Hierarchy

ActewAGL's asset management system aligns with ISO 55001. This document covers the requirements of Clause 6.2.2, *planning to achieve asset management objectives*. Figure 1 shows the alignment of ASPs in the asset management system.

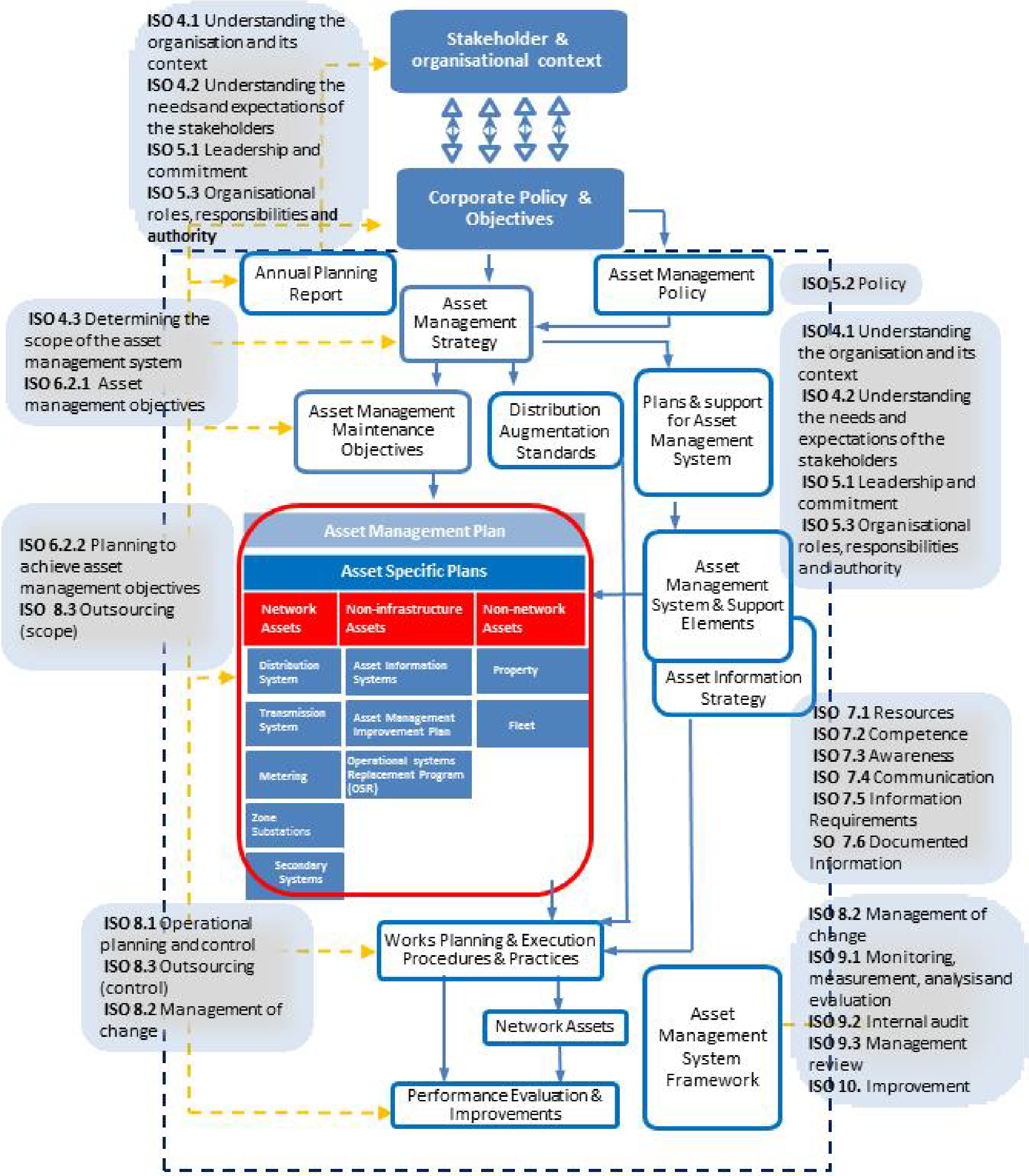

Figure 1: Asset management system structure

1 Executive Summary

The “Air Insulated Switchgear” (AIS) assets are installed in ActewAGL 132kV/11kV and 66kV/11kV zone substations and 132kV switching stations which are bulk supply points in the network. These substations supply 14,300 customers on average and are part of the 132kV transmission network in the ACT supplying the entire ACT electricity supply and part of the NSW transmission network. This equipment is required to switch, protect, isolate and earth electrical plant and networks. Their reliable operation is fundamental to the safe and reliable operation of the network.

AIS assets have a very high cost of failure and must be replaced before complete failure to manage the environmental, safety and network reliability risks. Assets in this ASP operate at 132kV and 66kV and include the following asset types:

- Oil and SF6 outdoor circuit breakers
- Instrument transformers - Current Transformers and Voltage Transformers;
- Isolators;
- Earth switches;
- Busbars;
- Surge Diverters.

This ASP evaluates options for the management of this asset class with a risk based approach to determine the optimal strategy that satisfies the asset class objectives. A summary of the options considered are:

- Option - 0: Reactive Strategy – effectively adopt a “run to failure” approach;
- Option - 1: Existing Strategy – routine planned maintenance and condition monitoring with condition assessment for life extension and replacement;
- Option - 2: Reduce Cost Strategy – asset management premised on condition based asset maintenance and replacement to lower the lifecycle cost of assets relative to the existing strategy with minimal, if any impact on risk exposure;
- Option - 3 Reduce Risk Strategy – increased maintenance and replacement targeted to deliver a reduced level risk for assets with the highest risk.

The preferred option from this evaluation is option – 2 Reduce Cost Strategy. This option satisfies the asset class objectives, manages risk to acceptable level and is the least TOTEX cost option. This option includes an innovative condition based maintenance strategy for circuit breakers enables costs to be reduced by scheduling intrusive maintenance (costly and complex) only on assets which need intrusive maintenance which is determined by non-intrusive testing.

The evaluation also considers alignment of maintenance and renewal activities with associated asset classes and network augmentation projects for delivery efficiency including the dependency Augmentation Project, “Decommissioning Fyshwick Zone Substation”.

Key challenge: Fyshwick zone substation 66kV switchgear – end of life. This switchgear has been forecast to reach end of life in 2019-24 and cannot continue to operate reliably presenting unacceptable risk. This switchgear has exceeded its design life, is experiencing increasing operational defects and declining performing. This switchgear is no longer supported by the manufacturer and spare parts are not available which has resulted in un-repairable defects effecting operational performance.

This substation is proposed to be decommissioned in the 2019-24 period removing the need to replace the 66kV switchgear assets. Refer to augmentation project “Decommission Fyshwick Zone Substation”.

Assuming Fyshwick zone substation 66kV switchgear assets are decommissioned, no major asset replacement projects are forecast during 2018-24 with CAPEX comprised of refurbishment of 132kV oil circuit breakers. Compared to the 2014-19 regulator period, CAPEX is reduced by 92% for 2019-24. Higher expenditure in the 2014-19 period included the replacement of the Hitachi OFDT1-145F1FK 132kV circuit breaker fleet at end of life. In 2017 there is 1 unit remaining at Belconnen zone substation and is planned to be decommissioned as part of a 132kV line augmentation project and is therefore not included in this forecast.

The estimated 2018-24 budget for CAPEX and OPEX is presented in Table 1.

Total Budget	2018/19	2019/20	2020/21	2021/22	2022/23	2023/24
CAPEX	**170,000**	**170,000**	**170,000**	**136,000**	**68,000**	**0**
OPEX	**139,491**	**140,666**	**140,384**	**128,110**	**104,799**	**136,713**
Planned Maintenance	71,515	69,435	89,985	60,785	38,125	71,341
Unplanned Maintenance	25,010	25,010	25,010	25,010	25,010	25,010
Condition Monitoring	42,966	46,221	25,389	42,315	41,664	40,362

Table 1: OPEX and CAPEX Optimised Program of Work Budget

The decommissioning costs of Fyshwick zone substation 66kV switchgear is not included in the CAPEX forecast in this ASP. If the augmentation project does not proceed in 2019-24 this switchgear will require replacement at an additional cost of $2.74m CAPEX in 2019-24. This cost estimate is shown in Appendix B.

2 Asset Class Overview

This ASP covers the Air Insulated Switchgear asset class, which lies within the zone substations asset portfolio. The asset types within this class are as follows:

- 132kV and 66kV Circuit Breakers;
- 132kV and 66kV Current Transformers;
- 132kV and 66kV Voltage Transformers;
- 132kV and 66kV Isolators;
- 132kV and 66kV Earth Switches;
- 132kV and 66kV Surge Diverters;
- 132kV and 66kV Busbars.

For details of the asset groups contained within this asset class, refer to section2.3 Asset Functions.

2.1 Asset Class Objectives

This ASP strategy follows the overall ActewAGL asset management strategy and asset management objectives. The asset class strategy is an integral part of the asset management strategy, with the overall objective to provide safe, reliable and cost effective supply of electricity to customers and compliance with regulatory requirements.

This Air Insulated Switchgear ASP has been developed in alignment with the asset management strategy and seeks to meet objectives in the following categories shown in Table 2.

Asset Management Objectives	Asset Class Objectives
Responsible	
• Achieve zero deaths or injuries to employees or the public • Maintain a good reputation within the community • Minimise environmental impacts, for example bushfire mitigation • Meet all requirements of regulatory authorities, such as the AER as outlined in the NER, and the ACT Utilities (Technical Regulations) Act 2014.	• No death or injury to employees or the public • Achieve 0 complete asset failures • Ensure design and acceptance for new assets complies with standards
Reliable	
• Tailor maintenance and renewal programs for each asset class based on real time modelling of asset health and risk • Meet network SAIDI and SAIFI KPIs • Record failure modes of the most common asset failures in the network	• Achieve 0 complete asset failures • Achieve detailed understanding of asset health and incorporation into asset modelling • Measure SAIDI and SAIFI contribution from this asset class • Review ASP at least every 5 years • Record and complete asset failure investigations within 20 business days
Sustainable	
• Enhance asset condition and risk modelling to optimise and implement maintenance and renewal programs tailored to the assets' needs • Make prudent commercial investment decisions to manage assets at the lowest lifecycle cost • Integrate primary assets with protection and automation systems in accordance with current and future best practice industry standards • Deliver the asset class PoW within budget.	• Achieve 90% data completeness for minimum asset data requirements • Incorporate online circuit breaker condition monitoring into modelling • Deliver PoW outlined in this plan
People	
• Proactively seek continual improvement in asset management capability and competencies of maintenance personnel.	• Provide support for 132kV/66kV circuit breaker analyser testing equipment • Promote continual improvement

Table 2: Asset class objectives

The strategy and ASP must be practical in the sense that they can be implemented with sufficient flexibility to satisfy current and future requirements of the ActewAGL network and must be cost effective and efficient with regard to technical and human resources.

2.2 Asset Groups

The AIS assets are classified in terms of asset function and lifecycle characteristics. The following table provides a broad-based classification of asset groups within this asset class.

Asset Class	Air Insulated Switchgear
Asset Groups	132kV and 66kV Circuit Breakers 132kV and 66kV Instrument Transformers 132kV and 66kV Isolators 132kV and 66kV Earth Switches 132kV and 66kV Surge Diverters 132kV and 66kV Busbars

Table 3: Asset Classification – AIS Assets

2.3 Asset Functions

The AIS assets comprise the majority of 132kV and 66kV outdoor equipment installed in zone substations. As an asset class they provide key functions essential to the reliable and safe operation of the zone substations and the network. As an asset class their high level functions are as follows:

- The interconnection of lines with zone substation major assets such as power transformers, capacitor banks etc.;
- Monitoring of network voltages and currents for load management and network protection and control;
- Provision of means for the safe access to network plant and equipment for works;
- Protection of high value assets from potentially damaging transient overvoltages.

Circuit Breakers

The load and fault (protection initiated) switching of 132kV and 66kV circuits.

Current Transformers

Monitoring of both steady state and transient currents on the 132kV and 66kV circuits for input to network protection and metering systems.

Voltage Transformers

Monitoring of both steady state and transient voltages on the 132kV and 66kV circuits for input to network protection, control, synchronising and metering systems.

Isolators

Provision of safe and efficient means of isolation of 132kV and 66kV assets within zone substations for access purposes.

Earth Switches

Provision of safe and efficient means of application of earths to 132kV and 66kV lines at zone substations for access purposes.

Surge Diverters
The protection of high value zone substation assets (usually power transformers) from hazardous transient overvoltage conditions, typically from lightning related voltage surges.

Busbars
Provision of major, high current capacity interconnection between circuits within zone substations.

2.4 Needs and Opportunities

The AIS asset class incorporates a number of discrete asset types with widely diverse construction types, deterioration drivers, modes of failure and different levels of inherent risk. As such the following section on “needs and opportunities” covers the AIS assets by type.

2.4.1 Circuit Breakers

The fleet of circuit breakers is comprised of three discrete construction types each with different characteristics as follows:

2.4.1.1 Minimum Oil Type

These circuit breakers are the oldest on the network ranging in age from 26 to 46 years (2017). They utilise insulating oil as their insulating and arc quenching medium and are heavily reliant upon gas generated by arcing within the oil during contact separation to complete an opening operation. They are vulnerable to a range of deterioration drivers and accordingly are maintenance intensive in terms of maintenance intervals and work scope.

Due to their design a failure condition can present a high risk of explosion and fire with widespread resultant risk to personnel and adjacent assets.

Needs

ASEA (ABB) type HKEYC 66kV Circuit Breakers
Of the five ASEA (ABB) type HKEYC60 66kV minimum oil circuit breakers installed at Fyshwick zone substation, four are in excess of 58 years of age, are considered to be approaching the end of their design life and have been assessed as being in poor condition. They are considered to present a significant risk of failure.

To most effectively assess options to mitigate the risks presented by these circuit breakers ActewAGL will undertake a program of detailed assessment of their condition and potential modes of failure (2017-19) to:

- Determine the areas where deterioration is apparent (e.g. mechanism, interrupter etc.);
- Assess the extent of the deterioration and its potential to impact on the performance and reliability of the circuit breakers;
- Determine options to address the risks presented by the observed deterioration such as:
  - Targeted refurbishment of the circuit breakers to extend their life;
  - Replacement of the circuit breakers prioritised on the basis of risk and condition.

The condition of the balance of the minimum oil circuit breakers will continue be monitored through the planned maintenance program which incorporates a suite of condition monitoring activities.

Opportunities

Enhanced Condition Assessment and Maintenance Activities

The rate of duty related deterioration, and hence the service life of the circuit breakers, is highly dependent upon the correct adjustment of a number of key parameters such as contact speed, damping, penetration and travel. The incorporation of contact movement analysis (time-travel analysis) into planned maintenance to ensure correct adjustment of these parameters would promote the likelihood of these assets achieving their design life.

Opportunity Replacements

Planned replacement of older units on an opportunity basis (during works on related assets) would reduce the overall population of these circuit breakers along with the related maintenance costs and inherent risks a failure would present. It would also provide spare components with which to service those of the fleet that remain in good condition.

2.4.1.2 Live Tank SF6 Type

These circuit breakers utilise sulphur hexafluoride (SF6) gas as their insulating and arc quenching medium. They of a more modern design, have fewer deterioration drivers and are less maintenance intensive that the minimum oil circuit breakers. Whilst an internal flashover would present a risk of explosion its likelihood is relatively low due to the use of SF6 gas instead of oil and also due to the fitment of pressure relief provisions to these circuit breakers.

Needs

ABB Type LTB145D1 132kV Circuit Breakers

The fleet of ABB type LTB circuit breakers consists of 10 units, four of which are less than 10 years of age with the balance ranging from 22 to 24 years of age (2017). Three of the older units have exhibited SF6 leakage problems which, on the basis of recent inspections, have been attributed to corrosion of aluminium flanges on the poles which has compromised their sealing.

Early advice from the manufacturer attributes the corrosion to a likely type “issue” with the older circuit breakers. Works will be undertaken to address the existing leakage problems and further advice is being sought from the manufacturer as to measures to be taken to mitigate the risks presented by the remaining circuit breakers in this age group. The risk mitigation works will be undertaken as a matter of priority.

There is no evidence of similar or emerging defects with the balance of the fleet.

2.4.1.3 Dead Tank SF6 Type

The interrupter design, insulating medium and mode of operation of the dead tank circuit breakers (CBs) is very similar to that of their live tank counterparts.

The key differences between the two types are as follows:

- The interrupter in the dead tank type is enclosed within an earthed metal tank pressurised with SF6 gas whereas a live tank type has the interrupter housed in an insulating casing which is at line potential;

- The dead tank circuit breakers have integral current transformers (CTs) installed externally on the bushing turrets whereas the live tank circuit breakers are not fitted with CTs but typically have separate post type CTs installed immediately beside them.

The assessed condition of the dead tank fleet is good with no evidence of emerging defects. Therefore other than the planned maintenance program no other measures are deemed necessary over the period 2019-24 to manage their performance.

2.4.2 Current Transformers

2.4.2.1 Post Type, Oil Filled

The post type current transformers are of a “live tank” type construction and have an oil/paper insulation system. The typical life expectancy of and oil/paper insulation system is approximately 50 years but is dependent upon aging factors such as thermal stress, voltage stress and moisture ingress, all of which result in accelerated aging. By the nature of their design, post type current transformers operate at relatively high voltage stresses which are considerably greater than in power transformers. As such their insulation systems tend to deteriorate at a correspondingly greater rate.

Due to their design an internal insulation failure of a post type CT would be highly likely to result in explosion and fire and would present a major risk to personnel and adjacent equipment. (This mode of failure is not uncommon, with a number instances in other utilities over recent years)

Their condition is assessed via a program of oil sampling for analysis of quality and dissolved gases.

Needs

A significant number (69) of the older CTs in the age range 40 to 50 years have been identified as being in fair or poor condition. These will be subject to more detailed assessment for prioritisation of their replacements in the immediate future.

Opportunities

Refurbishment of post type CTs is neither technically nor economically viable therefore they require replacement at assessed end of life.

However, many of the post type CTs are installed in conjunction with the older minimum oil circuit breakers. These CTs will be replaced on an opportunity basis when the related circuit breaker is replaced.

2.4.2.2 Toroidal

Toroidal CTs are fitted externally to bushing turrets, typically on dead tank circuit breakers, outside the high voltage electric field. As such they have only low voltage insulation (typically epoxy or composite type material) and are of dry type (no oil) construction.

Due to their construction there is little in the way of condition monitoring for toroidal CTs other than physical inspection which is undertaken during maintenance of the associated circuit breaker.

The toroidal CTs have exhibited no evidence of deterioration or incidence of defects and as such no works outside physical inspection are planned for the 2019-24 period.

2.4.3 Voltage Transformers

Voltage transformers (VTs) have an oil/paper insulation system and, as with the post type CTs, operate at relatively high voltage stresses which are considerably greater than in power transformers. As such their insulation systems tend to deteriorate at a correspondingly greater rate than the nominal 50 year life expectancy for power transformers.

An internal insulation failure of a VT would be likely to result in explosion and fire and would present a major risk to personnel and adjacent equipment.

Their condition is assessed via a program of oil sampling for analysis of quality and dissolved gases.

Needs

A significant number (33) of the older VTs in the age range 40 to 50 years have been identified as being in critical condition. These will be subject to more detailed assessment for prioritisation of their replacements in the immediate future.

Opportunities

Refurbishment of VTs is neither technically nor economically viable therefore they require replacement at assessed end of life. To reduce the hazards presented by the explosive failure of an oil filled VT the option of using different construction VTs such as polymeric capacitor voltage transformers (CVTs) or dry type units will be investigated as replacement units. The use of voltage taps on bushings of adjacent plant will also be investigated as an alternative to VTs.

2.4.4 Isolators and Earth Switches

Isolators and earth switches are of a fairly simple design and have no graded insulation systems. As such their modes of failure are typically benign and present a low level of risk. They are subject to a program of planned maintenance which incorporates some condition monitoring activities on a two yearly basis. The maintenance interval is subject to a review by ActewAGL with a view to it being extended to four yearly.

A number of units assessed as being in critical condition will be subject to further investigation but, because of their benign modes of failure no wholesale refurbishment or replacement is warranted and the remedial works will be undertaken as planned maintenance activities.

Needs

Those units identified as in critical condition will be addressed through planned remedial maintenance.

Based on the outcome of the investigations of the root cause of the observed defects the scope of preventative maintenance will be reviewed to include additional works as deemed necessary.

Opportunities

Planned maintenance scopes will be reviewed with the intent of increasing the planned maintenance interval from two yearly to four yearly.

2.4.5 Surge Diverters

Surge diverters are subject to maintenance and condition assessment when the associated major plant (usually a power transformer) is maintained. Maintenance typically consists of cleaning of the insulating casing and condition assessment is comprised of inspection and measurement of insulation resistance (for each individual segment). For those surge diverters of “gapped” type internal construction moisture ingress can lead to their explosive failure. Modern zinc oxide types do not have this vulnerability.

Needs

A number of units have been assessed as being in critical condition. These will be subject to investigation and replaced as necessary. No wholesale replacements across the population are deemed necessary.

Opportunities

The “gapped” type surge diverters will be replaced with zinc oxide units on an opportunity basis.

2.4.6 Busbars

Busbars are subject to inspection and any remedial maintenance is undertaken on an opportunity basis when an interconnected item of plant is accessed for maintenance.

There are no emerging defects apparent with busbars and no change is envisaged to their ongoing management.

2.5 Associated Asset Classes

AIS assets have functional relationships with the following asset classes:

- Protection and SCADA systems;
- Zone Earthing;
- Power Transformers;
- Transmission assets;
- Ancillary Transformers;

2.5.1 Similar Functions

AIS assets, specifically circuit breakers, have similar functions to the following asset classes:

- Zone 11kV Switchboard Assembly;
- GIS and Mixed Technology Switchgear;

3 Asset Base

This section provides details of the ActewAGL asset base within this asset class, including age and condition profiles and the projected asset count.

3.1 Asset Base Summary

Table 4 gives details of ActewAGL's in-service (including system spares) zone air insulated switchgear as at April 2017.

Asset Type	Quantity	Design Life (yrs)	Average Age (yrs)	Oldest Age (yrs)
132kV, 66kV Oil Circuit Breakers	39	50	36	58
132kV LTCB Circuit Breaker SF6	10	50	16	24
132kV DTCB Circuit Breaker SF6	19	50	5	41
132kV & 66kV Current Transformer Oil Insulated	153	50	25	51
132kV & 66kV Current Transformer BCT	75	50	3	8
132kV & 66kV Voltage Transformer Oil Insulated	88	50	29	50
132kV & 66kV Isolator	149	50	35	58
132kV & 66kV Earth Switch	37	50	33	52
132kV Surge Diverter	6	50	40	47
Grand Total	**576**	**50**	**26**	**58**

Table 4: AIS Assets

3.2 Asset Service Life Expectancy

The design life of the AIS assets is 50 years. This is however affected by a range of aging factors as follows:

- Electrical loading;
- Thermal conditions;
- Moisture/contamination ingress into the insulation system (CBs, CTs, VTs);
- Exposure to overvoltage conditions (sustained or transient) - (CBs, CTs, VTs);
- Fault breaking duty (CBs).

3.3 Asset Age Profile

Figure 2 shows the age profile of the AIS assets.

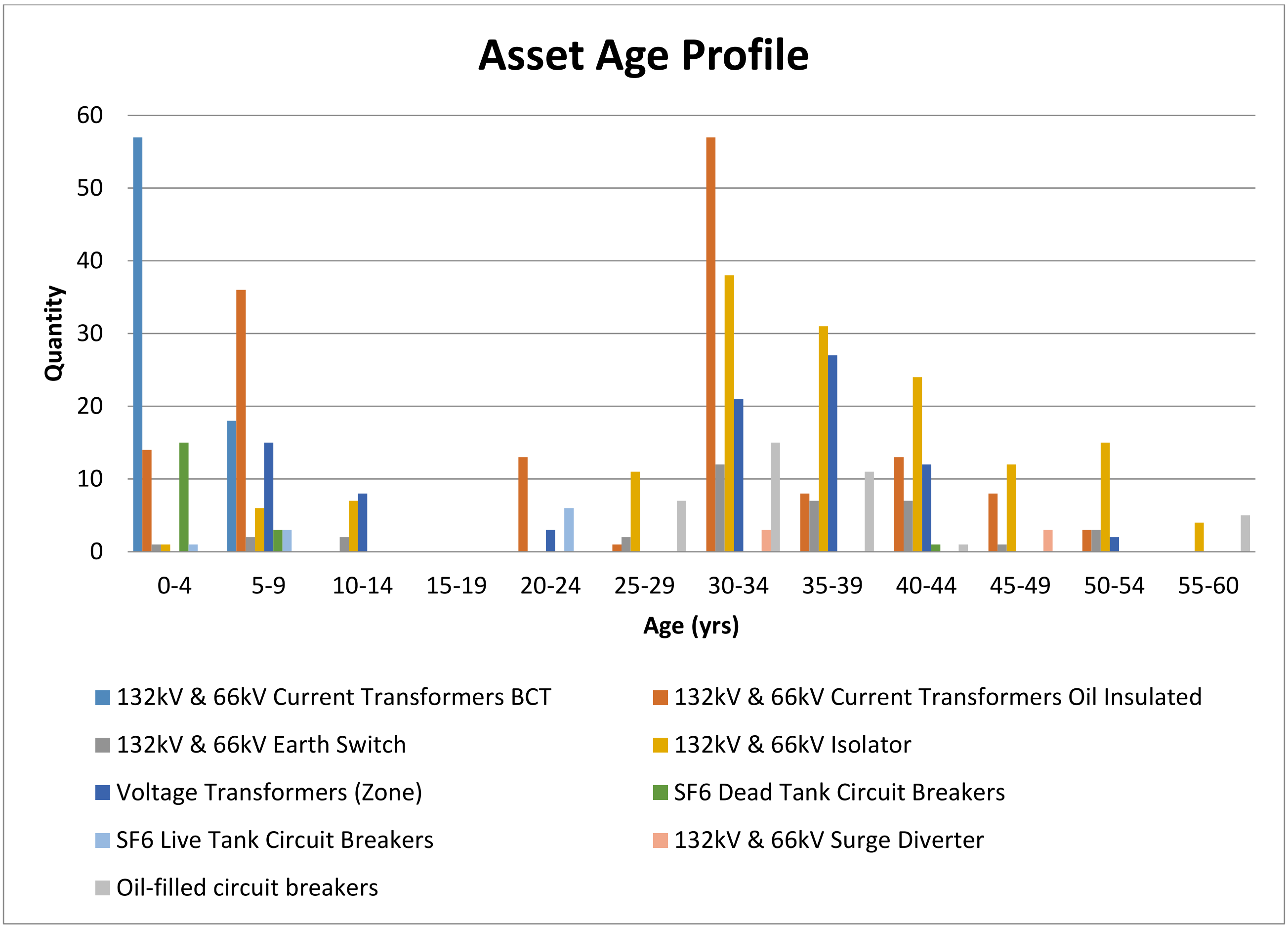

Figure 2: Age Profile of AIS Assets

3.4 Asset Condition Profile

Asset health represents the condition of assets and is an assessment of an asset's capacity to perform its function(s) at the required level of service. Asset condition is calculated using an age-based degradation model and modified by known asset condition, environmental or usage information. Table 5 shows asset health in 2017.

Asset Type	Manufacturer	Model	Asset Quantity	Asset Quantity - Critical Health 2018-24	Average Health 2017
132kV, 66kV Oil Circuit Breakers			**39**	**5**	**Fair**
	ABB		**3**	**0**	**Good**
		HLR145/2501E	3	0	**Good**
	ASEA		**36**	**5**	**Fair**
		HKEYC60/800	5	**5**	**Poor**
		HLR145/2501E	30	0	**Fair**
		HLR145/2002A2	1	0	**Fair**
132kV LTCB Circuit Breaker SF6			**10**	**0**	**Excellent**
	ABB		**10**	**0**	**Excellent**
		LTB145D1	10	0	**Excellent**
132kV DTCB Circuit Breaker SF6			**19**	**0**	**Excellent**
	GEC-ALSTOM		**18**	**0**	**Excellent**
		DT1-145F1FK	18	0	**Excellent**
	HITACHI		**1**	**0**	**Good**
		OFDT1-145F1FK	1	0	**Good**
132kV & 66kV Current Transformer Oil Insulated			**153**	**0**	**Good**
	ABB		**12**	**0**	**Good**
	TYREE		**62**	**0**	**Fair**
	KONCAR		**31**	**0**	**Good**
	ENDURANCE		**3**	**0**	**Poor**
	ALSTOM		**9**	**0**	**Excellent**
	CROMPTONGREAVES		**9**	**0**	**Excellent**
	ASEA		**25**	**0**	**Fair**
	PLESSEYDUCON		**2**	**0**	**Poor**
132kV & 66kV Earth Switch			**37**	**0**	**Good**
	ABB		**1**	**0**	**Excellent**
	ALSTOM		**1**	**0**	**Excellent**
	NGKSTANGER		**14**	**0**	**Good**
	BONARSTANGER		**9**	**0**	**Good**
	MCDONALD		**3**	**0**	**Fair**
	MORLYNNSTANGER		**4**	**0**	**Good**
	DICKSONPRIMER		**1**	**0**	**Fair**
	MORLYNNPOWER		**2**	**0**	**Good**
	LOWBONARSTANGER		**1**	**0**	**Good**
	AK POWER		**1**	**0**	**Excellent**

Table 5 continued on next page

Asset Type	Manufacturer	Model	Asset Quantity	Asset Quantity - Critical Health 2018-24	Average Health 2017
132kV & 66kV Isolator			149	5	Good
	ABB		1	0	Excellent
	ALSTOM		5	0	Excellent
	NGKSTANGER		56	0	Good
	BONARSTANGER		20	0	Good
	MCDONALD		14	0	Fair
	MORLYNNSTANGER		20	0	Good
	DICKSONPRIMER		11	0	Fair
	MORLYNNPOWER		11	0	Good
	LOWBONARSTANGER		4	0	Good
	ALM		6	5	Fair
	AK POWER		1	0	Excellent
132kV & 66kV Voltage Transformer Oil Insulated			88	2	Good
	ABB		3	0	Excellent
	TYREE		54	0	Good
	KONCAR		20	0	Excellent
	ALSTOM		3	0	Excellent
	ARTECHE		6	0	Good
	ENDURANCE ELECTRIC		2	2	Fair
Grand Total			495	12	Good

Table 5: AIS Asset Condition Summary

The following assets are identified in poor condition approaching end of life with increasing risk. The asset class objective is zero catastrophic failures and therefore the strategy must implement condition monitoring and planned replacement of these assets when they reach end of life condition ‘critical’. The Fyshwick zone substation 66kV switchgear assets are forecast to reach end of life in 2018-24. These assets are:

- Circuit Breakers - ASEA HKEYC60/800
- Isolators - ALM VSB
- Voltage Transformers – ENDURANCE ELECTRIC

The asset class health profile in 2017 is summeries in Figure 3.

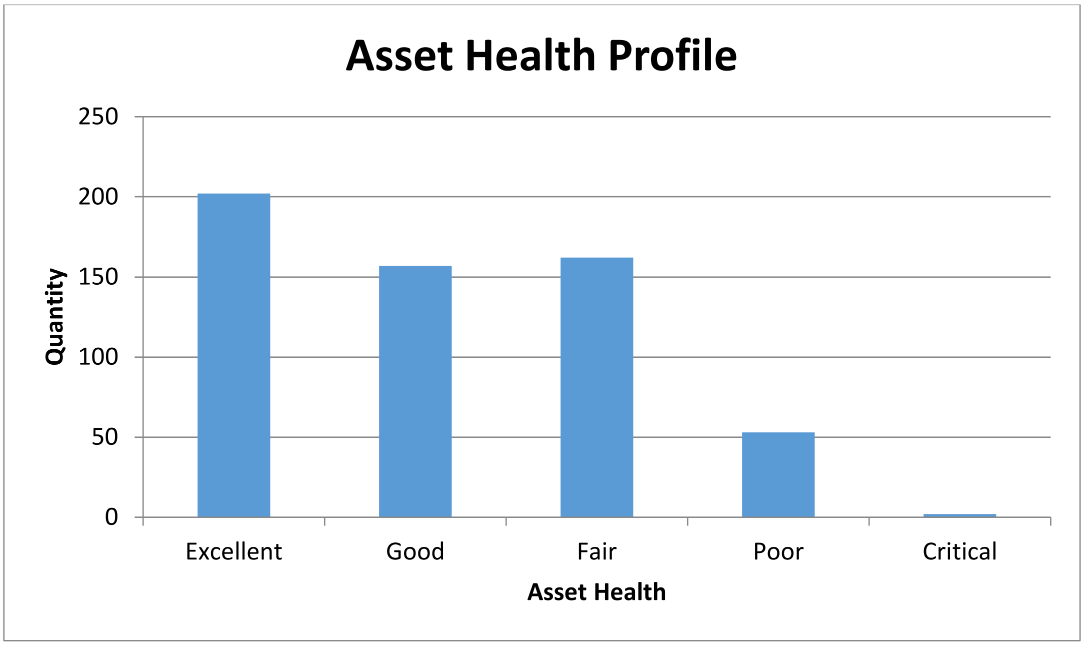

Figure 3: AIS Asset Condition Asset health profile – 2017

Those assets assessed as being in “Poor” or “Critical” condition will be subject to further investigation to assess options for remedial activities.

3.5 Projected Asset Count

The projected asset count is an estimate of the numbers of respective asset types within the AIS asset class by year. It will be affected by network augmentation works primarily but also by any dedicated spare units held.

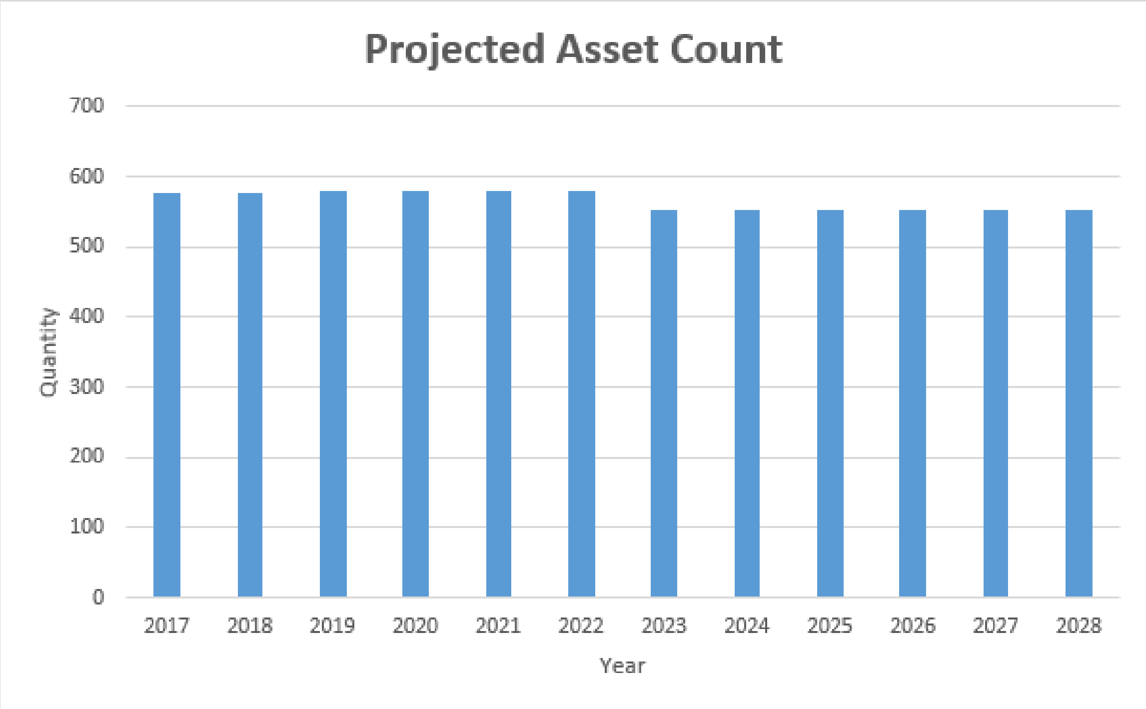

Figure 4: AIS Projected Asset Count

3.5.1 Network Augmentation and Infrastructure Development

Network augmentation projects affecting the asset class population are detailed in the following sub-sections.

3.5.1.1 Gold Creek Zone Augmentation

Gold Creek zone substation augmentation project includes the addition of 1 x 132kV DTCB and 1 x 132kV Isolator. The planned commissioning date for these assets is 2019/20.

3.5.1.2 Belconnen Zone Augmentation

Belconnen zone substation augmentation project includes the addition of 1 x 132kV DTCB and 1 x 132kV Isolator. The planned commissioning date for these assets is 2019/20.

3.5.1.3 Fyshwick Zone Substation Decommissioning

Fyshwick zone substation augmentation project includes decommissioning Fyshwick zone substation in the 2019-24 regulatory period. This removes all 66kV switchgear from the asset base, 5 x 66kV Oil Circuit Breakers, 5 x 66kV Isolators, 2 x 66kV Voltage Transformers and 15 x 66kV Current Transformers. The planned decommissioning date for these assets is 2022/23.

3.6 Data Sources

Effective asset management relies on accurate asset information. The Asset Management System uses the following data sources for asset management:

- Geospatial Information System (GIS) Including Asset Inventory – esri GIS
- Works Management System - Cityworks
- Advanced Distribution Management System (ADMS) – Schneider Electric

- Finance Management System - Oracle
- Asset Management & Modelling System - Riva Modelling

3.6.1 Data Quality

3.6.1.1 Data Completeness

- Asset inventory is complete and all assets are identified
- Asset data such as make, model and serial numbers is not complete for this asset group
- Condition and performance data is not complete and being collected during maintenance
- All assets proposed to be installed or removed during the regulatory period are considered
- Historic financial history specific to this asset class is available from June 2014 only.

3.6.1.2 Data Accuracy

The following outlines data quality issues affecting the quality of this ASP:

- Maintenance and condition assessment data quality for analytical asset modelling
- Asset make and model data is not complete

Data Improvements

- Improve maintenance and condition assessment data quality
- Capture asset make and model data
- Capture asset fault history and root cause analysis of faults
- Improve process and systems for data capture into asset modelling systems

4 Asset Performance Requirements

This section details the reliability and performance requirements of the zone substation air insulated switchgear asset class.

4.1 Failure Modes

4.1.1 Failure Mode Effects Analysis (FMEA)

This ASP uses a risk based methodology, based on the ActewAGL Failure Mode and Effects Analysis (FMEA) approach to improving reliability and reducing maintenance costs. A series of factors contributing to probability and consequence of failure for respective asset classes are identified, analysed and rated by a team of cross-functional subject matter experts. These are then utilised as inputs to the overall risk cost calculations.

4.1.2 Deterioration Drivers and Common Modes of Failure

Tables in the following section for each asset type summarise their common modes of failure. They have been configured to show the assessed effects of each failure mode in terms of severity, occurrence and detection which are the inputs to Riva. Column 6 shows the resultant generated Risk Priority Number (RPN)

The following summarises the deterioration drivers and common failure modes for zone air insulated switchgear assets by asset type;

4.1.2.1 132kV & 66kV Circuit Breakers – Minimum Oil

Deterioration Drivers

- External insulator/bushing surface condition due to contamination/environmental factors;
- Degraded insulating medium (oil) condition from switching duty and moisture ingress;
- Deterioration of internal solid insulation due to moisture ingress, heat (loading), surface contamination, erosion due to burning (arcing);
- Erosion of main contacts resulting in high resistance and overheating;
- Erosion of arcing contacts resulting in excessive arcing and damage to interrupter components;
- Erosion/burning of arc control chambers/baffles resulting in degraded arc quenching capability;
- Deterioration of lubrication due to drying or contamination over time;
- Incorrect adjustment resulting in incorrect operating speed, damping, contact travel;
- Mechanical deterioration of mechanism components from duty;
- Increased mechanical wear due to degraded dashpot functionality;
- Erosion or contamination of auxiliary contacts due to duty with resultant open control circuits;
- Contamination of mechanism/drive linkages resulting in degraded functionality (damping, travel, latch engagement etc.
- Interrupter seal deterioration which results in:
    - o Oil leakage/moisture ingress (minimum oil type)

Failure Modes

Failure Mode	Description	Severity	Occurrence	Detection	RPN
Complete – Fail to Insulate - Internal flashover; - External flashover; - Explosive failure of circuit breaker	Cause: - Loss of insulating medium; - Contamination of insulating medium; - Inadequate contact separation; Effect: - Fire/Explosion - Customers off supply - Cost to replace/repair with collateral damage	8	3	5	120
Complete – Fail to break fault current - complete failure of circuit breaker	Cause: - Mechanism failure; - Interrupter failure; - Drive linkage failure; - Slow operation; - Inadequate contact travel/speed; Effect: - Fire/Explosion - Customers off supply - Cost to replace/repair with collateral damage	8	3	5	120
Partial – Fail to open (respond) or slow operation protection command	Cause: - Defective control circuits; - Defective auxiliary switches; - Defective trip coil(s); Effect: - Backup protection operation, outage to large number of customers	2	4	6	46

Table 6: 132/66kV Minimum Oil Circuit Breaker Failure Modes

4.1.2.2 132kV & 66kV Circuit Breakers – SF6 LTCB and DTCB

Deterioration Drivers

- External insulator/bushing surface condition due to contamination/environmental factors;
- Degraded insulating medium (SF6) condition from switching duty and moisture ingress;
- Deterioration of internal solid insulation due to moisture ingress, heat (loading), surface contamination, erosion due to burning (arcing);
- Erosion of main contacts resulting in high resistance and overheating;
- Erosion of arcing contacts resulting in excessive arcing and damage to interrupter components;
- Erosion/burning of arc control chambers/baffles resulting in degraded arc quenching capability;
- Deterioration of lubrication due to drying or contamination over time;
- Incorrect adjustment resulting in incorrect operating speed, damping, contact travel;
- Mechanical deterioration of mechanism components from duty;
- Increased mechanical wear due to degraded dashpot functionality;
- Erosion or contamination of auxiliary contacts due to duty with resultant open control circuits;
- Contamination of mechanism/drive linkages resulting in degraded functionality (damping, travel, latch engagement etc.
- Interrupter seal deterioration which results in:
  - Loss of SF6 gas/contamination of SF6 with moisture/atmospheric air;

Failure Modes

Failure Mode	Description	Severity	Occurrence	Detection	RPN
Complete – Fail to Insulate - Internal flashover; - External flashover; - Explosive failure of circuit breaker	Cause: - Loss of insulating medium; - Contamination of insulating medium; - Inadequate contact separation; Effect: - Fire/Explosion - Customers off supply - Cost to replace/repair with collateral damage	8	2	5	80
Complete – Fail to break fault current - complete failure of circuit breaker	Cause: - Mechanism failure; - Interrupter failure; - Drive linkage failure; - Slow operation; - Inadequate contact travel/speed; Effect: - Fire/Explosion - Customers off supply - Cost to replace/repair with collateral damage	8	2	6	96
Partial – Fail to open (respond) or slow operation protection command	Cause: - Defective control circuits; - Defective auxiliary switches; - Defective trip coil(s); Effect: - Backup protection operation, outage to large number of customers	2	3	7	36

Table 7: 132/66kV SF6 Circuit Breaker LTCB & DTCB Failure Modes

4.1.2.3 Isolators and Earthing Switches

Deterioration Drivers

- Moisture ingress to main contact assemblies resulting in corrosion and an increase resistance of main current path;
- Deterioration of main contacts due to contamination or burning with resultant increase in resistance of main current path;
- Excessive wear of contact system due to lack of lubrication, misalignment, contamination of contact surfaces;
- Overheating of contact assemblies resulting in loss of contact spring tension and further increase in resistance of main current path (runaway effect);
- Corrosion of drive system resulting in inadequate movement (failure to close or open correctly);
- Corrosion or erosion of auxiliary switches which cause disruption to control circuits (failure to close/open, loss of status signal);
- Mechanical deterioration of flexible conductors (braids) resulting in breakage of strands and increase in resistance of main current path;
- Surface contamination of support insulators resulting leakage current to earth (isolators only);
- Mechanical deterioration of support insulators (moisture ingress and internal corrosion of metallic fittings, corrosion/binding of bearings etc.) resulting damage/breakage;
- Mechanical misalignment of fixed and moving contacts - Potential for poor closing/ increased contact resistance.

Failure Mode	Description	Severity	Occurrence	Detection	RPN
Complete – Excessive leakage current results in flashover to ground	Cause: - Contaminated surface of insulators; - Cracking or deterioration of insulator surface; Effect: - Fire - Customers off supply - Health and safety hazard	2	5	6	30
Complete – High resistance in main current path	Cause: - Corrosion of main current path; - Poor connection of fixed and moving contacts; - Deterioration of contacts Effect: - Fire - Customers off supply - Health and safety hazard	2	4	6	48

Failure Mode	Description	Severity	Occurrence	Detection	RPN
Partial – Fail to open or close	Cause: - Mechanical failure; - Jammed drive linkages; - Faulty control circuit (ROIs); Effect: - Delayed isolation/restoration of network	1	4	6	24
Partial – High resistance to earth (Earth Switch)	Cause: - Corrosion of main circuit; - Deteriorated braids/connection from earth switch blade to main earth connection; Effect: - Electric shock, death or injury	7	2	6	84
Partial – Fail to open or close (Earth Switch)	Cause: - Mechanical failure; - Jammed drive linkages; - Misaligned main contact system prevents closing; Effect: - Delayed isolation/restoration of network	1	4	6	24

Table 8: Isolator and Earth Switch Failure Modes

4.1.2.4 Instrument Transformers – Oil Filled

Deterioration Drivers

- Age and thermal deterioration of paper/oil insulations system;
- Moisture ingress to insulation system (oil and solid);
- Oil leakage – loss of insulation medium;
- Contamination of external surface of insulator (particularly for CTs);
- Overvoltage conditions (transient – lightning, sustained steady state);
- Excessive burden on secondary circuit – (VT);
- Open circuit secondary – (CT) will result in excessive voltage across the winding and likely insulation damage;
- Open circuit voltage tapping connection (CT);
- Ineffective earth connection will result in variable voltage rises on the main insulation and possible damage;
- Moisture ingress to secondary terminal box and corrosion of secondary connections.

Failure Mode	Description	Severity	Occurrence	Detection	RPN
Complete – Internal flashover	Cause: - Loss or contamination of insulating medium; - Poor grading between internal and external stress; (CT) - Deterioration of insulation Effect: - Fire/Explosion - Customers off supply - Health and safety hazard	8	4	6	192
Complete – External flashover	Cause: - Contaminated, deteriorated, or damaged insulator surface; Effect: - Customers off supply - Health and safety hazard	7	4	7	196
Partial – Loss of secondary output	Cause: - Open circuit secondary Effect: - Customers off supply	2	2	8	32

Table 6: Oil Filled Instrument Transformer Failure Modes

4.1.2.5 Bushing Current Transformers (BCT) Non-Oil Filled

Overview

Whilst performing the same electrical function as their oil filled counterparts these current transformers are of a much simpler design and hence present far fewer deterioration drivers and failure modes. They are physically located outside the earth plane and external to the high voltage bushings as such they do not have graded, solid primary insulation systems nor flammable liquid insulation medium.

Deterioration Drivers

- Open circuit secondary – will result in excessive voltage across the winding and likely insulation damage;
- Mechanical damage to CT enclosure may result in damage to the CT toroid or secondary connections;
- Moisture ingress to secondary terminal box and corrosion of connections

Failure Modes

Failure Mode	Description	Severity	Occurrence	Detection	RPN
Partial – Loss of secondary output	Cause: - Open circuit secondary Effect: - Customers off supply	2	2	2	8
Partial – Physical damage to enclosure	Cause: - Loss/degradation of mechanical protection to BCT enclosure Effect: - Repair/replacement - Outage to customers	2	1	1	2

Table 7: Non-oil Filled Toroidal Instrument Transformer Failure Modes

4.1.2.6 Surge Diverters

Deterioration Drivers

- Corrosion of metallic components leading to moisture ingress to the body of the surge arrester;
- Operation of surge diverter with internal free moisture;
- Surface deterioration/contamination of the surge diverter external (insulator) casing;

Failure Modes

Failure Mode	Description	Severity	Occurrence	Detection	RPN
Complete – Insulation failure	Cause: Spark gap type surge diverter operation with internal free moisture results in major overpressure and explosive failure Effect: - Fire/Explosion - Customers off supply - Cost to replace/repair with collateral damage	8	3	7	168
Complete – External flashover	Cause: Contaminated/deteriorated surface results in flashover Effect: - Fire/Explosion - Customers off supply - Cost to replace/repair with collateral damage	4	2	7	56
Partial – Loss of sealing	Cause: Corrosion leads to loss of sealing and risk of moisture ingress Effect: -	2	2	7	28

Table 8: Surge Diverter Failure Modes

4.1.2.7 Busbars

Deterioration Drivers

- Corrosion of metallic components leading to moisture ingress to support insulator and mechanical failure;
- Surface contamination of support insulators leads to creepage failure/flashover;
- Corrosion of busbar fittings and high resistance in main current path;
- Non-functioning of expansion joints due to any of corrosion, mechanical damage, contamination leading to mechanical damage to support insulators.

Failure Modes

Failure Mode	Description	Severity	Occurrence	Detection	RPN
Partial – Support insulator failure	Cause: Moisture ingress to insulator fittings causes corrosion and loss of mechanical strength Effect: - Degradation of overall mechanical strength of busbar; - Vulnerable to mechanical damage for through fault;	5	4	4	80
Partial – Flashover	Cause: Contamination of insulator surface causes creepage failure/flashover Effect: - Protection trips bus; - Extended bus outage for duration of repairs (replacement/cleaning of insulator)	4	2	3	18
Partial – High resistance in main current path	Cause: Corrosion of busbar fittings results in high resistance joints and overheating Effect: - Overheating of bus and connections	3	2	2	12

Failure Mode	Description	Severity	Occurrence	Detection	RPN
Partial – Mechanical damage to expansion joints	Cause: Impeded functioning of busbar expansion joints results in mechanical stress on support insulators due to busbar thermal expansion Effect: - Mechanical damage to insulators.	3	2	7	42

Table 8: Busbar Failure Modes

4.2 Asset Utilisation

This section details the utilisation level of the assets. Depending on the asset type, the level of utilisation will have a direct impact on service life and condition.

4.2.1 Capacity

The capacity of the AIS assets relates to operating parameters and is determined by the equipment ratings. Equipment ratings are supplied by manufacturers and include rated voltage, rated continuous current, rated short time withstand current and rated breaking current. To ensure their reliability, assets must be operated within their respective ratings.

ActewAGL's current operating and network planning philosophy for these assets is to not exceed the equipment design ratings. This is justified by the current utilisation level which is discussed in section 4.2.2.

4.2.2 Utilisation

AIS assets operate continuously and the utilisation is driven by network demand and network configuration. This in turn is driven by the daily load cycle which itself varies throughout the year. Assets may be exposed to short term higher loading during contingent network configurations.

Utilisation for this asset class is a measure of;

- Network demand on the equipment capacity rating in MVA or Amps.

4.3 Risk and Criticality

This section details the criticality of AIS assets and the exposure to risk.

4.3.1 Asset Criticality

Zone substations are bulk supply points in the network where asset failures present significant risk to distribution and transmission network performance As an asset group the AIS is critical to the reliable and safe operation of zone substations and the transmission network.

Air insulated switchgear assets supply a large number of customers where an asset failure effects 14,300 customers on average resulting in large impacts on SAIFI and SAIDI network performance. The consequence of failure is so large that measures are taken during design and operation to reduce network reliability risk by incorporating a 132kV bus-section circuit breaker. A 132kV bus section circuit breaker reduces number of customers at risk of an outage thereby lowering the network reliability consequence of asset failures. The risk reduction for substations with this type of design is model for each asset in the asset risk model.

The combined financial, operations, reputation, safety and environmental risk cost of a complete failure of an air insulated switchgear asset can be over $12.1m. This is a significant cost and is more than four times the planned replacement cost.

However, within the asset group the respective asset types typically have a hierarchy of criticality as follows:

Circuit Breakers

Circuit breakers perform load and fault switching functions for the network. Through their ability to clear network faults, minimise fault current magnitude and duration they perform a critical function to maintain the safety of employees, members of the public and for ActewAGL assets both within zone substations and on the interconnected network. They also provide essential means for planned load switching to allow network reconfiguration for maintenance access to assets.

Current Transformers

Current transformers perform a critical function for measurement of the current in the circuits to which they are connected for both metering and protection purposes. They perform an essential function to detect fault related conditions and initiate (via protection relays) operation of circuit breakers for fault clearance.

Voltage Transformers

Voltage transformers provide the ability to monitor the voltage and phase relationship of the circuits to which they are connected. Their function is essential for network protection schemes and maintaining network voltages within prescribed limits.

Isolators

Isolators play no part in connection or disconnection of load switching or fault clearance but provide the most efficient and safe means for the electrical isolation of network assets for physical access. Their function is less critical than the circuit breakers and instrument transformers as other means of achieving isolations are available (such as removal of connections) but for issues of practicality, safety and cost are not preferred.

Earth Switches

Earth switches (like isolators) play no part in in connection or disconnection of load switching or fault clearance. They too provide the most efficient and safe means to connect an out of service (isolated) line to earth. Their function is less critical than the circuit breakers and instrument transformers as other means of application of earths are available (portable earths) but for issues of practicality, safety and cost are not preferred.

Surge Diverters

Surge arresters perform a critical function to protect key assets from damage due to transient overvoltage conditions (lightning impulses). They operate to divert such transient overvoltages to earth and limit the voltage at the asset protected to within its design capability. Their function is important to protect highly costly and critical assets.

Busbars

Busbars provide the interconnection between high voltage circuits within zone substations and as such they are of critical importance to the operation of the substations. Even with multiple busbars in service at a zone substation the unavailability of a single busbar would have a major impact on the station and present a significant risk to supplies from the station and to the interconnected network. Busbars, because of their interconnection to multiple circuits, are among the most critical assets within zone substations.

4.3.2 Geographical Criticality

Geographic factors do not affect the performance and reliability of AIS assets in AAD’s network. The geographical location effects the consequence of failure for environmental risk. Environmental risk of these assets is dependent on the bushfire risk and assets are categorised into three environmental risk zones, urban, Bushfire Abatement Zone (BAZ) and rural.

4.3.3 Asset Reliability

A high degree of reliability is required from the AIS assets given that they comprise the majority of the high voltage assets for conventional outdoor zone substations and, as a whole are required to operate continuously. By asset type the reliability requirements are as follows:

Circuit Breakers

Circuit breakers require a high degree of reliability in order to maintain the safety of the network and to the public. They are required to remain in service (closed) continuously, often for years, during which time they must also remain fully operational to clear faults on the network and to respond to planned switching requirements.

Current Transformers and Voltage Transformers

Where these are utilised for protection functions they are responsible for, among other things, the detection of a network fault condition and initiation, via protection, of the tripping of the circuit breaker(s) for fault clearance. In this regard their reliability must be equivalent to that of the circuit breaker. (the required degree of reliability is reduced where the fault detection is undertaken by duplicate instrument transformers). Current and voltage transformers utilised solely for metering duties do not require the same degree of reliability.

Isolators

Isolators are required to remain in service (closed) continuously usually only being operated (opened and closed) for maintenance activities on other assets. They require a high degree of reliability in terms of their current carrying capacity (in the closed condition). Given, however that circuit isolations can be obtained by other means if necessary, their required operational reliability is less than that of the circuit breakers and instrument transformers.

Earth Switches

Earth switches are required to operate only for maintenance access at which time they are closed on to the high voltage circuit concerned. For normal network operation they have no electrical connection to the high voltage circuits. Therefore, given also that earths can be applied by other means, the reliability of earth switches is less than that of circuit breakers and instrument transformers.

Surge Diverters

Whilst the incidence of transient overvoltages due to lightning is fairly low, a high degree of reliability is required of surge diverters in order to mitigate the risk of major damage to high value assets that they protect. In that context surge arresters are required to remain in service continuously to protect the circuits to which they are connected.

Busbars

Busbars, by their nature of interconnecting multiple circuits within zone substations, including power transformers, have the highest reliability requirement of the AIS asset group.

Failure Summary

In the past 10 years this asset class has experienced 1 complete failure and a total of 6 partial failures. A summary of failures for this asset class is shown in Table 9.

Failure Type	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Complete	0	0	0	0	0	0	0	1	0	0
Partial	0	0	0	0	1	0	0	1	2	2

Table 9: AIS Asset Failures

The complete failure in 2015 was a 132kV VT failure.

Complete

Complete failures result in the asset being unrepairable requiring replacement to restore the network. The most common types of complete failures are:

- Insulation failure
- Circuit breaker interrupter failure

Partial

Partial failures are repairable through maintenance or refurbishment. The most common types of partial failures are:

- Circuit breaker slow operation
- Circuit breaker no operation
- SF6 gas leak
- Circuit Breaker operating mechanism failure

5 Asset Management Strategy Options

This section outlines the options considered for the management of AIS assets throughout their lifecycle and their assessed relative merits. It recommends an asset specific strategy that best supports the business asset management policy, strategy and objectives.

5.1 Option Evaluation Methodology

5.1.1.1 Financial Cost/Benefit Assessment

The options are assessed in terms of their resultant OPEX, CAPEX and risk exposure costs. The option specific financial assessments are generated as outputs from the Riva system which are then factored into the options assessment process.

5.1.1.2 Qualitative Risk Assessment

Qualitative assessments of the risks and consequences inherent to each option have been undertaken utilising the standard methodology from the ActewAGL “Energy Networks Risk Assessment Tables”.

5.2 Options Discussion

Options for the asset specific strategies are evaluated against their relative cost, risk, benefits, and consider trade-offs between capital and operational expenditure to deliver the asset management objectives. The options that have been considered are as follows:

- Option 0 – Reactive Strategy;
- Option 1 – Existing Strategy;
- Option 2 – Reduce Cost Strategy;
- Option 3 – Reduce Risk Strategy.

5.2.1 Option 0 – Reactive Strategy

Under this option no controls such as proactive maintenance, condition assessment or planned replacement are applied. Any maintenance or asset replacement is purely reactive and is undertaken when the asset is no longer suitable for service which may be due to any of:

- A major failure that is not repairable;
- Unacceptably high incidence of defects that impact on the asset serviceability which, although repairable, are not economically or technically viable.

Thus this option incorporates:

- Reactive (unplanned) maintenance;
- Reactive replacement of (failed) assets.

5.2.1.1 Risk Outcomes

The risk outcomes of this option increase over time as the condition of the assets deteriorate through the combined aging effects and as a consequence their reliability also deteriorates as they approach the end of their expected life.

Circuit Breakers

Circuit breakers, in particular oil types, are relatively complex and maintenance intensive. This option would, in a relatively short time, result in very high probability of the onset of failure conditions and exposure to resultant risk in terms of personnel and asset and safety, network reliability, financial costs (including penalties and litigation) and corporate reputation.

Instrument Transformers

Instrument transformers associated with protection systems have a similar level of criticality to the circuit breakers but given their relatively low maintenance requirements it is expected that the onset of failure conditions under this strategy would be later than that of circuit breakers. The risk exposures presented by the failures would, however be similar to that of the circuit breakers.

Busbars and Surge Diverters

Busbars and surge diverters also have minimal maintenance requirements so, under this strategy it is expected that failure instances would also be delayed. Failures would have a significant impact on network reliability and risk to high value assets.

Isolators and Earth Switches

This strategy would impact on the operability of isolators and earth switches which would ultimately result in an increase in their cost of ownership over time. There would be likely to be little impact on their reliability and resultant risks.

The summary of risks are:

- 22 High rating asset class risks
- Complete failure risk exposure cost – Exceeds $12.1m

A qualitative risk assessment of this option highlights the inherent risks (no controls) of this asset class and the risk exposure. This is shown in Table 10.

		Option 0 – Do Nothing Strategy				
Likelihood	Almost Certain					
	Likely	Low 4	Medium 8	High 8	High 4	
	Possible	Low 2	Medium 10	Medium 2	High 10	
	Unlikely	Low 1	Low 8		Medium 5	
	Rare	Low 6	Low 2			
		Negligible	Minor	Moderate	Major	Severe
		Consequence				

Table 10: Risk Assessment – Option 0

A quantitative risk assessment for this option has been modelled to estimate the risk exposure and is shown in Figure 5.

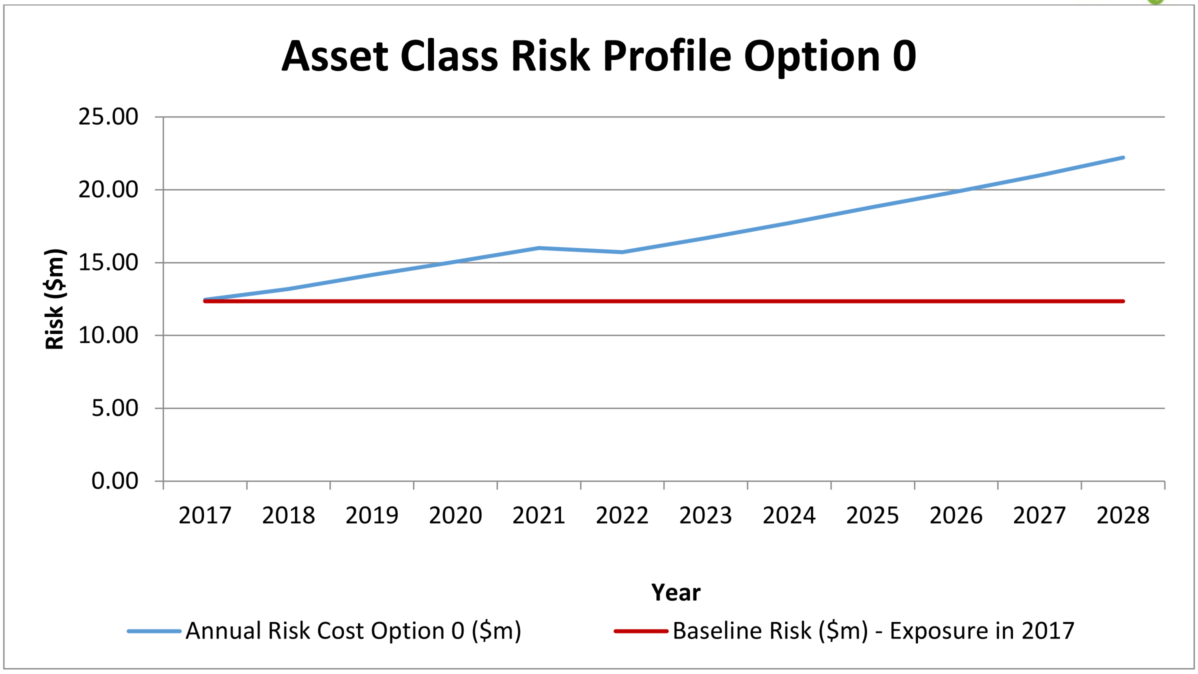

Figure 5: Risk-Cost Analysis – Option 0

5.2.1.2 Summary of Option Benefits

This option delivers the least OPEX and CAPEX at least in the early part of the asset life. CAPEX will continue to be deferred as OPEX and risk costs escalate as the assets deteriorate through their life.

5.2.1.3 Summary of Option Dis-benefits

This option delivers the following disbenefits (negative outcomes):

- Non-compliance with regulatory obligations;
- Inconsistent with contemporary industry practice and prudent asset management;
- Very high risk exposure in terms of safety, environment, network reliability, asset replacement costs and costs resulting from consequential damage;
- Unpredictable and inefficient OPEX and CAPEX and resource utilisation;

5.2.2 Option 1 - Existing Strategy

This option covers the existing strategy as applied to management of the AIS assets. It is premised upon the use of planned maintenance, condition monitoring, refurbishment and planned replacement in order to maximise the reliable service life of the assets. It looks to manage the risks presented as the assets age through considered CAPEX and OPEX trade-offs which incorporate:

- Planned maintenance scheduled on time intervals;
- Condition monitoring integrated into planned maintenance activities;
- Asset life extension which incorporates refurbishment where viable and, on an opportunity basis, the replacement of discrete components with modern counterparts; (e.g. bushings)
- Planned, proactive replacement of assets on the basis of asset condition, risk, cost of ownership and opportunity;

This strategy looks to quantify individual asset condition, probability of failure and resultant risk as a means for the ranking of assets relative to the risk they present and to provide the basis of programs for their mitigation.

The mitigation will typically be achieved by asset refurbishment or replacement. In both instances the assets will be replaced when they reach critical condition. Opportunity based replacements are also undertaken under this strategy subject to favourable cost benefit analysis.

5.2.2.1 Risk Outcomes

This option enables the risks presented by deterioration of the assets to be mitigated through the combination of:

- Planned maintenance;
- Condition monitoring;
- Planned replacement/life extension which is driven by the assessed condition and relative risks presented by asset performance deterioration/unreliability.

The summary of risks are:

- 0 high rating asset class risks reduced from 22 for Option 0.

A qualitative risk assessment of this option highlights the risks for this option. This is shown in Table 10.

Likelihood		Option 1				
	Almost Certain					
	Likely		Medium 2			
	Possible	Low 2	Medium 4			
	Unlikely	Low 4	Low 14	Medium 8	Medium 9	
	Rare	Low 7	Low 8	Low 2	Medium 10	
		Negligible	Minor	Moderate	Major	Severe
		Consequence				

Table 11: Risk Assessment – Option 1

A quantitative risk assessment for this option has been modelled to estimate the risk exposure and is shown in Figure 6.

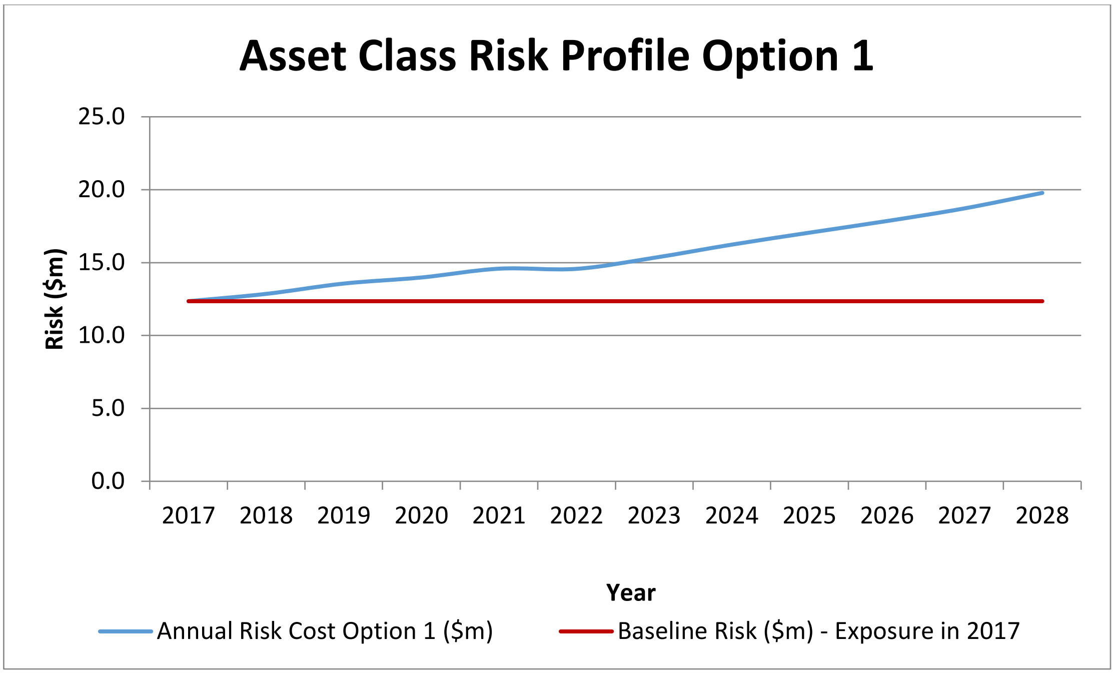

Figure 6: Risk Cost Analysis - Option 1

5.2.2.2 Summary of Option Benefits

This option delivers the maximum reliable service lives across the asset class whilst minimising their cost of ownership in terms of OPEX, CAPEX and risk costs.

5.2.2.3 Summary of Option Disbenefits

Inherent to this option is the ongoing operational costs associated with the condition monitoring activities. This necessitates careful review in order to optimise the stage of life at which this expenditure is implemented (for each asset type). If implemented early then the expenditure will be unnecessary and premature. If implemented late it will result in undetected incipient failure conditions and an incre4ased exposure to the risks they present.

5.2.3 Option 2 – Reduce Cost

This option evaluates a scenario of reduced cost for this asset class. It considers opportunities to reduce costs when compared to the existing strategy (option 1). For this option the maintenance schedule for 132kV/66kV circuit breakers and 132kV/66kV isolators and 132kV earth switches are changed.

132kV/66kV Circuit Breakers

For 132kV and 66kV circuit breakers there's opportunity to reduce lifecycle costs while increasing asset reliability. Intrusive maintenance of these assets performed by Option 1 is expensive and can be prone to reducing reliability if not done correctly. These assets rarely operate to clear faults and perform minimal operations during their life ActewAGL's network resulting in slower degradation of the assets and opportunity to defer major maintenance or refurbishment.

This strategy uses two classes of maintenance, class 1 (minor) and class 2 (major). Class 1 maintenance is performed every 4 years which includes condition assessment. The outcome of this testing will determine if class 2 maintenance is required and is scheduled accordingly.

Class 2 maintenance is intrusive maintenance which includes dismantling of the circuit breaker and replacement of parts as necessary. It's estimated not all circuit breakers tested will require class 2 maintenance.

132kV/66kV Isolators and Earth Switches

Maintenance of 132kV/66kV isolators is changed from 2 to 4 years which aligns maintenance schedules of other equipment in the same bay therefore optimising network outages. ActewAGL's network exists in a low pollution environment and maintenance records show low defect rates (<4% maintenance reports have defects since 2014) for isolators. This change also aligns maintenance practices with manufacturer recommendations and other Australian utilities.

5.2.3.1 Risk Outcomes

This option enables the risks presented by deterioration of the assets to be mitigated through the combination of:

- Planned maintenance aligned to the condition monitoring outcomes;
- Condition monitoring;
- Planned replacement/life extension which is driven by the assessed condition and relative risks presented by asset performance deterioration/unreliability.

This option has marginal increase in risk compared to option 1 however retains 0 high rating asset class risks. The risk increase is due to reduced maintenance on isolators and earth switches and transitioning to condition based maintenance from time based maintenance for 132kV/66kV circuit breakers. Condition based maintenance is estimated to detect any defects and only schedule intrusive maintenance or refurbishment where required thereby reducing maintenance costs.

A qualitative risk assessment of this option highlights the risks for this option. This is shown in Table 12.

		Option 2				
Likelihood	Almost Certain					
	Likely		Medium 2			
	Possible	Low 2	Medium 4			
	Unlikely	Low 5	Low 15	Medium 10	Medium 15	
	Rare	Low 6	Low 7		Medium 4	
		Negligible	Minor	Moderate	Major	Severe
		Consequence				

Table 12: Risk Assessment – Option 2

A quantitative risk assessment for this option has been modelled to estimate the risk exposure and is shown in Figure 7.

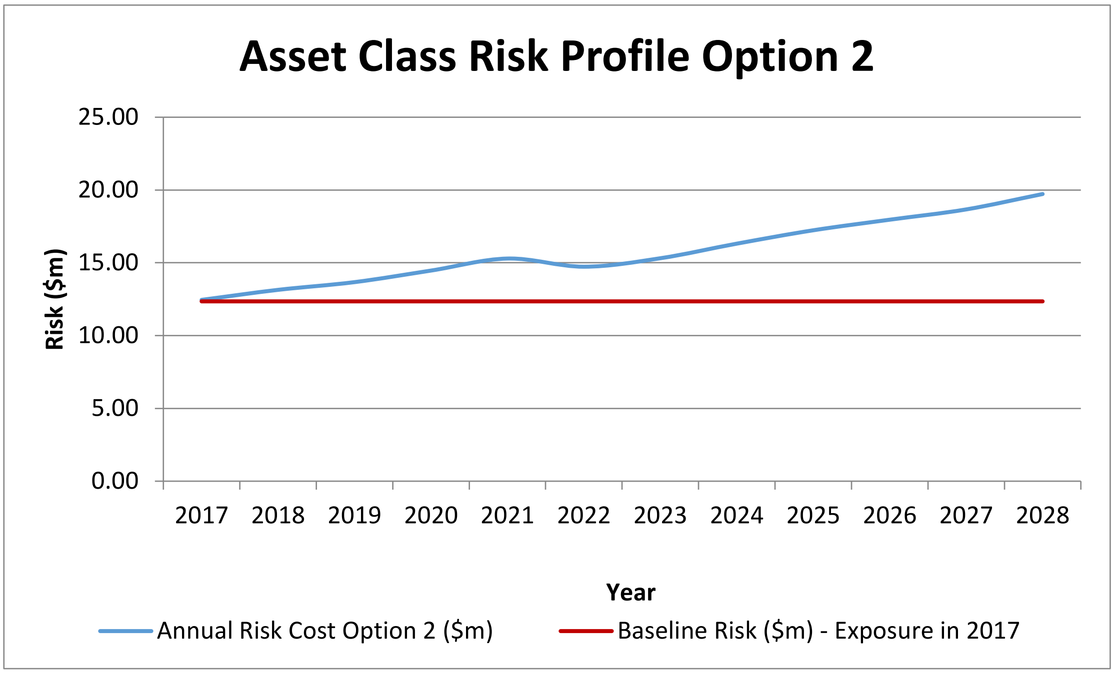

Figure 7: Risk Cost Analysis - Option 2

5.2.3.2 Summary of Option Benefits

This option results in the following “benefits”:

- Reduced CAPEX through target refurbishment for 132kV/66kV circuit breakers determined from testing;
- Intrusive maintenance is only scheduled when required thereby reducing the risk of faults introduced by intrusive maintenance;
- Reduced OPEX for 132kV/66kV isolators through increased maintenance intervals.

5.2.3.3 Summary of Option Disbenefits

This option results in the following “disbenefits”:

- The success of this strategy is dependent upon the collection, storage and timely analysis of the condition monitoring outcomes/information from the assets. The analysis processes, to be effective must include review of discrete measurements and trending of results over time.
- Rapid onset defect or failure conditions may not be detected within the condition monitoring or maintenance intervals.

5.2.4 Option 3 – Reduce Risk

This option reduces the risk presented by unavailability/failure of the assets. It takes a more conservative maintenance and refurbishment/replacement regime than the other options. This option includes the following:

Oil Circuit Breakers

- Planned maintenance as follows:
  - Two Yearly
    - Mechanism maintenance, lubrication, functional checks, condition monitoring incorporating oil analysis, timing, IR;
    - Outcomes of CM determine any additional maintenance
  - Six Yearly
    - Major maintenance including mechanism and interrupters;
- Replace based on condition monitoring at the onset of “critical” condition

SF6 Circuit Breakers (LTCB and DTCB)

- Planned maintenance as follows:
  - Two Yearly
    - Mechanism maintenance, lubrication, functional checks, condition monitoring incorporating SF5 analysis, timing, IR;
    - Outcomes of CM determine any additional maintenance;
  - Six Yearly
    - Major maintenance including mechanism and interrupters;
- Replace based on condition monitoring at the onset of “critical” condition

Instrument Transformers

- Maintain condition monitoring interval at 4 years for those assessed as in fair or better condition and decrease to 12 monthly for those assessed as in poor condition;
- Undertake replacement prioritised by oil analysis results of units assessed as critical
- Planned maintenance including insulation resistance, main current path resistance (CTs) and oil analysis when related circuit breaker is maintained;
- Replace other units at the onset of assessed critical condition.

Isolators and Earth switches

- Planned maintenance on 2 yearly interval;
- Replacement or refurbishment when incidence of repeat defects is noted, low spares availability;

Busbars

- Planned maintenance including cleaning of support insulations and ductoring of expansion joints on 6 yearly basis;

Surge Diverters

- Planned maintenance incorporating cleaning of casings, measurement of insulation resistance of each section and recording of operations when related plant is accessed for maintenance;
- Replace based on condition monitoring at the onset of “critical” condition.

5.2.4.1 Risk Outcomes

This option enables the risks presented by deterioration of the assets to be mitigated through the combination of:

- Planned maintenance aligned to the condition monitoring outcomes;
- Condition monitoring;
- Planned replacement/life extension which is driven by the assessed condition and relative risks presented by asset performance deterioration/unreliability.

This option reduces the risk compared to option 1 and has 0 high rating asset class risks. Risk is reduced by increased condition monitoring when assets approach end of life and replacement of assets in better condition when compared to strategy 1. These changes increase the likelihood of detecting imminent failure and reduce the likelihood of partial or complete failure near the end of life.

A qualitative risk assessment of this option highlights the risk for this option. This is shown in Table 13.

		Option 3				
Likelihood	Almost Certain					
	Likely		Medium 2			
	Possible					
	Unlikely	Low 5	Low 11	Medium 8	Medium 7	
	Rare	Low 8	Low 15	Low 2	Medium 12	
		Negligible	Minor	Moderate	Major	Severe
		Consequence				

Table 13: Risk Assessment – Option 3

A quantitative risk assessment for this option has been modelled to estimate the risk exposure and is shown in Figure 8.

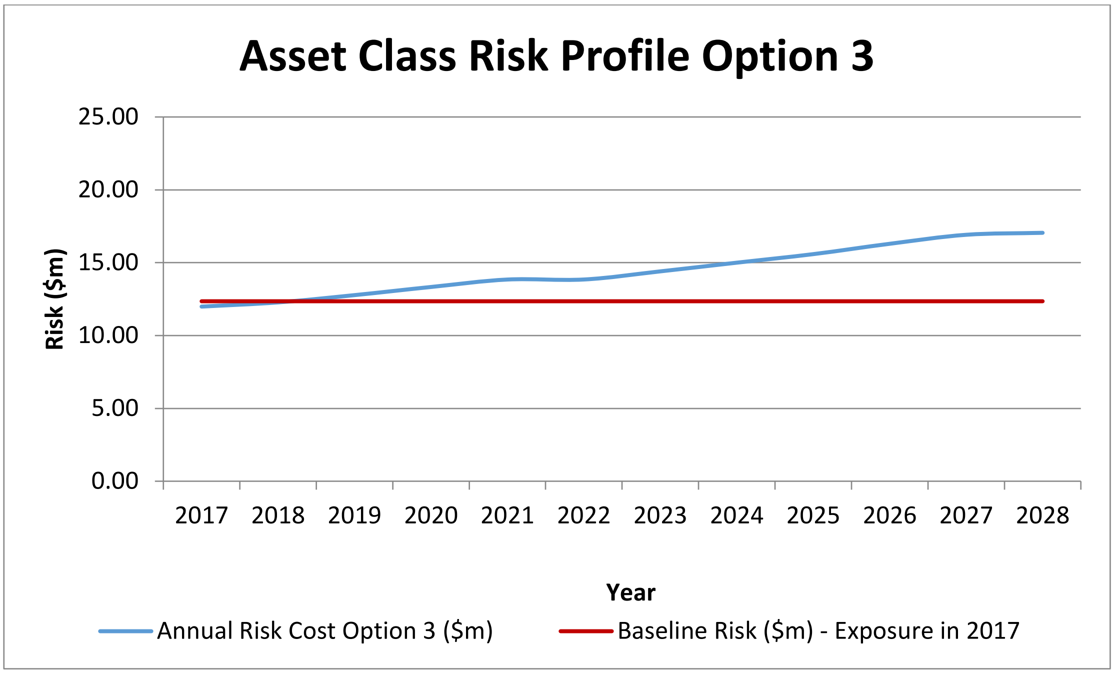

Figure 8: Risk Cost Analysis Option 3

5.2.4.2 Summary of Option Benefits

This option delivers a risk averse outcome with the result that the risk of asset failures and consequently the related costs are reduced through the conservative management regime applied to the assets.

5.2.4.3 Summary of Option Disbenefits

This option results in:

- Increased, ongoing operational costs due to the conservative maintenance and condition monitoring regime;
- Possible premature capital expenditure due to early refurbishment or replacement of assets.

5.3 Option Evaluation

This section provides a summary comparison of the evaluations of the options.

5.3.1 Engineering & Risk Evaluation

The key hazardous failures for zone air insulated switchgear assets include

Option 0 – Reactive strategy does not meet the asset class objectives and has no controls for high risk assets with very high consequence of failure. Complete failure of assets in this class is not acceptable since these failures are likely to result in catastrophic consequences. Assets in this class especially circuit breakers contain complex mechanical systems requiring regular maintenance to ensure they continue to operate reliably and condition monitoring is fundamental in identifying assets for replacement prior to failure.

Option 1, 2 & 3 are proactive strategies utilising planned maintenance, condition monitoring and planned asset renewal to ensure the reliable and safe operation. These strategies satisfy the asset class objectives, control risk to an acceptable level and are technically feasible.

Option 1

Option 1 has a traditional intrusive maintenance strategy for circuit breakers which are expensive and complex when compared to condition based maintenance strategy. This strategy has been satisfactory for oil circuit breakers which have required replacement of components to maintain performance. Replacement of these components require dismantling of the circuit breaker.

SF6 circuit breakers are approaching major maintenance and intrusive maintenance is not preferred unless required. These circuit breakers are more reliable than oil circuit breakers and in AADs network have few operations and are rarely exposed to fault based operations. If performance is satisfactory and no components are worn out, intrusive maintenance of SF6 circuit breakers will provide negligible or no benefit and may introduce faults through intrusive maintenance.

This option manages assets at an acceptable risk.

Option 2

Option 2 - Reduce cost utilises a condition based maintenance strategy for circuit breakers to diagnose condition degradation and defects through testing. Intrusive maintenance is only scheduled on assets which require maintenance determined through testing. This is expected to reduce the cost for SF6 circuit breakers and prevent maintenance induced faults by not undertaking intrusive maintenance unless required. Approximately half the oil circuit breaker fleet has undergone refurbishment requiring replacement of components and therefore intrusive maintenance is planned for these assets.

This strategy also reduces OPEX costs by reducing the maintenance on isolators which is justified through performance testing through past maintenance and reference to manufacture recommended maintenance cycles.

This option utilises innovative condition based maintenance for circuit breakers to reduce the lifecycle cost and manages assets at an acceptable risk.

Option 3

Option 3 – Reduce risk incorporates additional maintenance, condition monitoring and earlier replacement of assets when the probability of failure is lower thus reducing risk. Additional maintenance activities including testing of busbars and surge diverters. These assets are currently monitored through full substation inspections including thermovision and Partial Discharge (PD) testing to detect defects without the need for additional maintenance.

For this option maintenance of circuit breakers is also increased. Past performance of circuit breakers has been good and benefits from additional maintenance is estimated to be minimal.

5.3.2 Financial Evaluation

Financial comparison of technically feasible and acceptable risk options are summarised in Table 14. This summary includes forecast budget CAPEX and OPEX for the period 2018-24 and for comparison the 10 year and 30 year NPC of TOTEX and risk exposure.

Option	Budget ($m) 2018-24			NPC ($m) 10 yrs			NPC ($m) 30 yrs			Average Annual Risk 30 years ($m)	Rank
	TOTEX	CAPEX	OPEX	TOTEX	Risk	TOTEX + Risk	TOTEX	Risk	TOTEX + Risk		
Option 0	-	-	-	-	91.41	-	-	317.18	-	28.75	-
Option 1	2.42	1.31	1.10	2.51	85.19	87.70	6.40	230.67	237.08	19.37	3
Option 2	1.54	0.71	0.83	1.33	86.51	87.85	3.53	231.81	235.34	19.43	2
Option 3	2.38	0.71	1.66	2.89	80.16	83.05	6.44	193.17	199.60	15.66	1

Table 14: Cost and Risk Strategy Options Summary

The financial comparison ranks options giving more emphasis to the lowest TOTEX cost option.

The graph in Figure 9 provides an overview of long term risk exposure for all options.

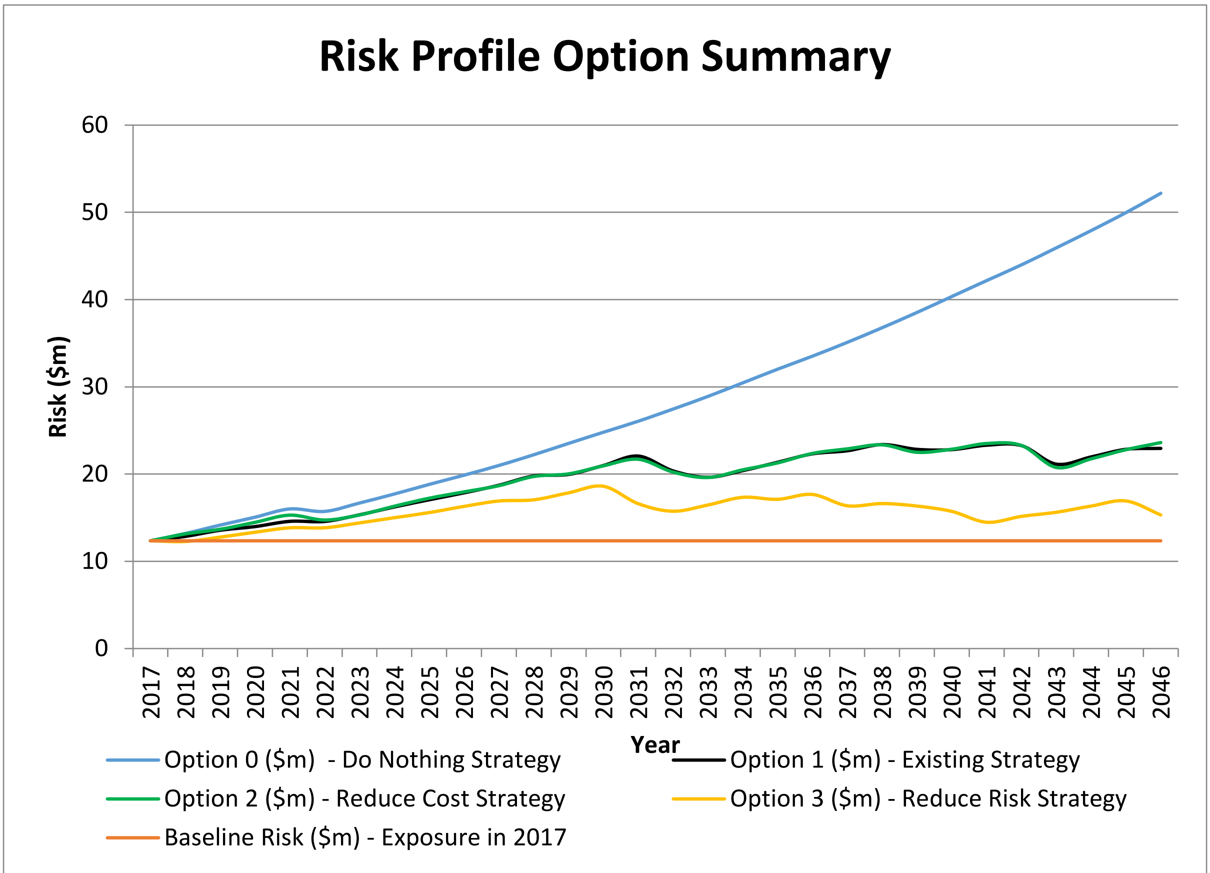

Figure 9: Risk Profile Comparison – AIS

5.3.3 Corporate Criteria Satisfaction Comparison

The evaluated options are also compared utilising the ActewAGL corporate methodology in which qualitative assessment is made of the extent to which each option satisfies the specified criteria as shown in the following table.

Criteria	Description and Weighting
Cost	This ranks the relative CAPEX and OPEX costs associated with the options. The weighting reflects the relative importance of this criterion.
Risk – Safety, Environmental, Reliability, Other	The extent to which the option provides mitigation/controls to risks identified. The weighting reflects the relative importance of this criterion.
Strategic Objectives	The extent to which the option meets the requirements of the asset management strategic objectives. The weighting reflects the relative importance of this criterion.
Innovation/Benefits	The extent to which the option provides business benefits including but not limited to information or intelligence to support innovative asset management and network operation. The weighting reflects the relative importance of this criterion.

Table 15: Option Evaluation Scoring Criteria

	Criteria				*Option Score*
	Cost	*Risk*	*Strategic Objectives*	*Innovation/ Benefits*	
Criteria Weighting	***30%***	***30%***	***30%***	***10%***	***100%***
***Option 0** - Do nothing Strategy*	*Not considered - rating not provided*				
***Option 1** - Existing Strategy*	*2*	*2*	*3*	*2*	*77%*
***Option 2** - Reduce Cost Strategy*	*3*	*2*	*3*	*3*	*90%*
***Option 3** - Reduce Risk Strategy*	*1*	*3*	*2*	*2*	*67%*

Table 16: Scoring Matrix

Scoring Key			
0	Fatal flaw	1	Unattractive
2	Acceptable	3	Attractive

5.4 Recommended Option

This section provides and overview of the recommended option and its outcomes for the period 2019-24.

5.4.1 Recommendation

The recommended option is Option 2 – Reduce Cost. This option satisfies the asset class objectives, manages risk to an acceptable level and delivers the outcomes which most completely satisfy the Corporate Criteria.

Options 1, 2 & 3 in the financial comparison manage risk to an acceptable level for both short and long term forecasts. With emerging disruptive technologies, uncertainty of future load at zone substations and potential for stranded assets, emphasis is given to the option with the least TOTEX cost. Option 2 has the least TOTEX cost in financial periods modelled and is the recommended option.

This option provides the means for the assets' reliable service life to be maximised while minimising asset total lifecycle cost through prudent innovative maintenance strategies including condition based maintenance refurbishment and replacement. In doing so, this strategy allows the exposure to business, environmental, safety and reliability risks to be managed to within acceptable levels and is the least TOTEX option.

Note: Fyshwick zone substation 66kV switchgear

This recommendation and budget assumes the Fyshwick zone substation 66kV switchgear will be decommissioned in 2019-24 in augmentation project, Decommission Fyshwick zone substation. For details refer to PJR – Decommission Fyshwick zone substation report. If this augmentation project does not proceed, the 66kV switchgear at Fyshwick zone substation will require replacement in 2022. The estimated cost of these works is $2.74m CAPEX in addition to the budget presented in this ASP.

5.4.2 Forecast Asset Health

Health profile is determined by asset condition and performance history. Condition is determined by the asset's capacity to meet requirements, asset reliability and its level of obsolescence. Obsolescence will be determined by maintenance requirements and availability of support from manufacturers.

The future health profile is the asset health profile at the end of the Regulatory Period, year 2024, under the recommended option to maintain risk exposure. This forecast is based on:

- Initial health profile
- Deterioration due to aging
- Deterioration where condition monitoring identifies specific risks for certain models of equipment
- Allowance made for replacement and refurbishments.

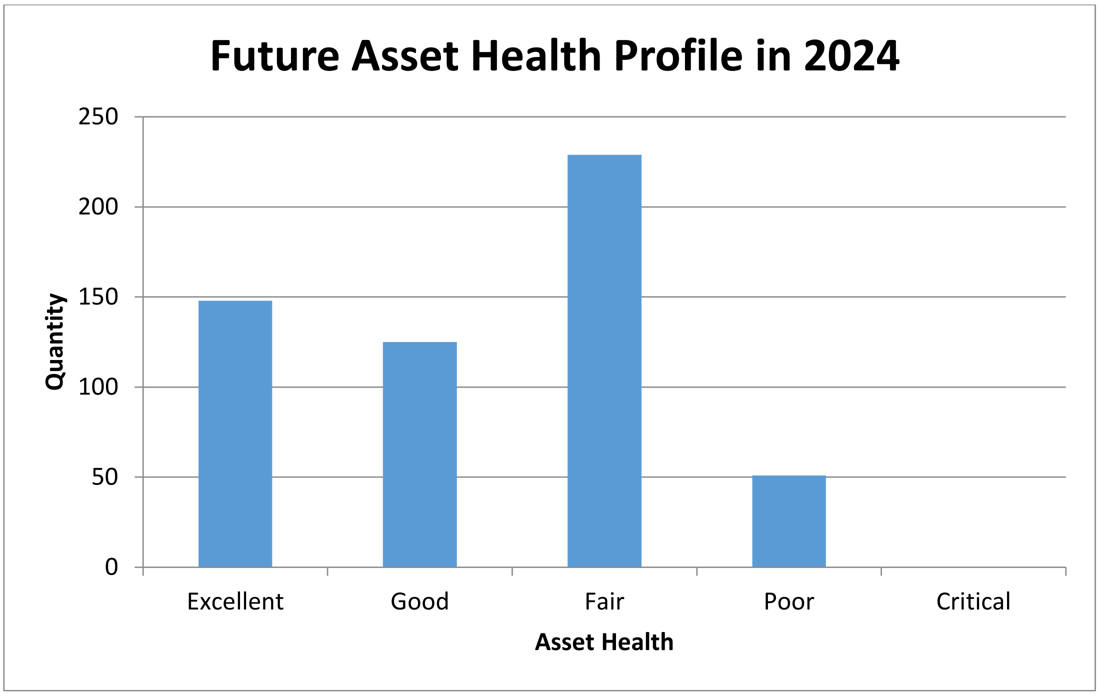

Figure 10: Asset Future Health Profile – AIS Assets

6 Implementation

This section provides implementation details for the recommended asset management strategy option.

6.1 Asset Creation Plan

Assets are added to the network from network augmentation activities. This ASP considers all forecast network augmentation projects that will impact upon the AIS asset class population.

This asset class has a low asset population and as such the number of assets replaced or added to the network is low. Equipment specification for asset additions and replacement are assessed on an case by case basis but includes:

- Preferred circuit breaker interrupter is SF6 type. Vacuum type interrupters to be investigated when commercially available for 132kV & 66kV networks.
- Use of polymer insulators and bushings
- Optical instrument transformers
- Consolidation of LTCB and oil filled CTs with DTCB and integrated CTs
- Disconnecting circuit breakers

6.2 Asset Maintenance Plan

The objective of the maintenance plan as embedded within this ASP is to economically achieve the longest possible reliable working life of assets. This is done through condition monitoring, preventative and remedial maintenance and has been adapted to the ActewAGL assets, operating environment and conditions.

6.2.1 Development

The maintenance plan is designed to achieve the objectives of this ASP. The following engineering techniques are used to develop the maintenance plan;

- Failure Modes and Effects Analysis (FMEA);
- Condition monitoring;
- Historic performance;
- Equipment manuals;
- Continuous review of asset performance and fine-tuning of maintenance triggers.

The planned maintenance regime for the AIS assets is shown in Table 17

Asset Type	Maintenance Task	Maintenance Trigger
Oil circuit beakers	Contact inspection/overhaul	Number of fault operations
	Minor maintenance (class 1)	8 yearly
	Major maintenance (class 2)	Based off condition assessment results from class 1 maintenance
SF6 circuit breakers	Minor maintenance (class 1)	8 yearly
	Major maintenance (class 2)	Based off condition assessment results from class 1 maintenance
Current Transformers	Oil analysis	4 yearly
	Maintenance	When related switchgear is maintained
Voltage Transformers	Oil analysis	4 yearly
	Routine maintenance	When related switchgear is maintained
Isolators and Earth Switches	Routine maintenance	4 yearly
Busbars	Routine maintenance	Opportunity basis
Surge Diverters	Routine maintenance	When related assets (zone transformers) are maintained

Table 17 AIS Asset Maintenance Interval Summary

6.2.2 Condition Monitoring

6.2.2.1 Thermal Surveys

Thermal surveys are undertaken across all asset classes, nominally twice yearly. They detect abnormal temperature rises on assets which may be indicative of incipient defect conditions. The outcome of thermal surveys will drive further investigations and remedial works as necessary.

6.2.2.2 Oil Type Circuit Breakers

The following condition monitoring is undertaken on the fleet of oil type circuit breakers during minor maintenance (class 1):

a. Oil Analysis
For the circuit breakers to operate correctly the quality of the insulating oil must be within prescribed limits for breakdown strength and moisture content. Oil samples are taken on a regular basis to assess the quality. Oil found to be outside acceptable limits will be either replaced or processed (filtered and dried) to restore it to the required performance.

b. Timing
Circuit breakers are subjected to analysis of their operating times and movement of their contact systems to ensure that all aspects of their operations are within parameters as prescribed by the manufacturer. Parameters measured include operating time (trip and close), contact speed (at separation), contact travel, movement damping, contact penetration, relationships between phases and between main and auxiliary contacts.

c. Contact Resistance
The ohmic resistance of the main circuit of each phase is measured to ensure it is within prescribed limits.

d. Insulation Resistance
The value of the DC resistance of the primary circuit to earth is measured as a qualitative indication of the condition of circuit breakers both before and after planned maintenance.

6.2.2.3 SF6 Circuit Breakers

The suite of condition monitoring activities for SF6 circuit breakers is very similar to that for oil type circuit breakers although the details vary due to the very different design of the SF6 type circuit breakers. The condition assessment undertaken for the SF6 circuit breakers is as follows:

a. SF6 Gas Analysis
For the circuit breakers to operate correctly the level of contaminants such as moisture and atmospheric air in the SF6 gas must be below prescribed limits. The presence of these contaminants may also indicate SF6 leakage. SF6 samples are taken on a four yearly basis to assess its quality.

b. Timing
SF6 circuit breakers are subjected to analysis of their operating times to ensure that all aspects of their operations are within parameters as prescribed by the manufacturer. Contact movement analysis is also undertaken but because of their design overall contact travel is less than for oil circuit breakers and damping characteristics are of less significance.

c. Contact Resistance
As for the oil type circuit breakers the ohmic resistance of the main circuit of each phase is measured to ensure it is within prescribed limits.

d. Insulation Resistance
As for the oil type circuit breakers the value of the DC resistance of the primary circuit to earth is measured as a qualitative indication of the condition of circuit breakers both before and after planned maintenance.

6.2.2.4 Voltage and Current Transformers

The following condition monitoring is undertaken on voltage and current transformers:

a. Oil Sampling
Oil samples are taken from instrument transformers on a regular basis for analysis of dissolved gasses and oil quality. The presence and relative concentration of “signature” gasses dissolved in the oil is used as an indicator of potential incipient fault conditions. In such events the frequency of oil sampling will be increased in order to more closely monitor and identify any trending.

b. Visual Inspection
Visual inspections of the assets are undertaken on an opportunity basis as a minimum during oil sampling.

c. Main Current Path Resistance (current transformers)
The ohmic resistance of the main current path of current transformers is measured to assess whether it is within prescribed limits;

d. Primary Circuit Insulation Resistance
The DC resistance of the primary circuit to earth is measured for assessment and trending purposes for current and voltage transformers.

6.2.2.5 *Isolators and Earthing Switches*

Due to their relatively simple design and construction the scope pf condition monitoring for isolators and earthing switches is limited to visual inspection and thermal surveys whilst in service and measurement of main current path ohmic resistance and primary insulation resistance during outages.

6.2.2.6 *Busbars*

Condition monitoring of busbars, again due to the simple construction, is limited to visual inspection and thermal surveys whilst in service and primary insulation resistance during maintenance. Main current path ohmic resistance measurements are taken across expansion joints during maintenance.

6.2.2.7 *Surge Diverters*

Condition monitoring of surge diverters is limited to measurement of their insulation resistance during maintenance. Measurement of their in service leakage current can also be undertaken if their connections to earth are suitably configured.

6.2.3 Planned Maintenance

All of the assets within the AIS class are subject to a program of planned maintenance, the intervals and scopes of which vary according to asset types as follows:

6.2.3.1 *Circuit Breakers*

For circuit breakers planned maintenance is driven by considerations of any or all of the following:

- Elapsed time;
- Number of operations;
- Number of fault switching operations; (fault duty);
- Outcomes of condition monitoring;

The outcomes of the condition monitoring activities undertaken during minor maintenance (class 1) may also drive the requirement for the major maintenance (class 2).

6.2.3.2 *Instrument Transformers*

Maintenance is usually undertaken on instrument transformers on an opportunity basis when a related major item of plant (circuit breaker, zone transformer etc.) is accessed for maintenance. It typically consists of cleaning of insulators, oil top up as necessary and repair of oil leaks where possible.

6.2.3.3 *Isolators and Earthing switches*

Maintenance is undertaken on isolators and earthing switches primarily on a time basis. It may also be initiated on the basis of observed condition. It typically comprises, functional checks, lubrication and checks of alignment and adjustment of contacts.

6.2.3.4 *Surge Diverters*

Maintenance is undertaken on surge diverters on an opportunity basis when a related major item of plant is accessed for maintenance. It typically is comprised of visual inspection and cleaning of the porcelain shell.

6.2.4 Unplanned Maintenance

Unplanned maintenance is undertaken for all AIS assets on a needs basis as determined from condition monitoring and inspection. Where possible it is undertaken as a planned activity and is aligned as far as possible with activities associated with interconnected assets.

6.3 Asset Renewal Plan

The asset renewal plan minimises risks presented by deterioration of the assets through planned refurbishment (where viable) or replacement of assets prior to the onset of poor reliability or complete failure. It applies asset condition information to trigger appropriate remedial action (refurbishment or replacement) and considers the following factors;

- Assessed critical condition and consequent poor performance and related risk exposure;
- Economic obsolescence (less economic to repair/refurbish than to replace with alternative product);
- Technological obsolescence (availability of spare parts and support);
- Safety risk (inherent to construction type, mode of failure etc.)
- Suitability of ratings for installed location.

The decision for replacement or refurbishment is undertaken for individual assets within each asset types in the AIS asset class on the basis of its assessed condition and associated risks.

6.3.1.1 Refurbishment

Opportunities for refurbishment are limited for some asset types within the AIS asset class. Due to their design refurbishment of surge diverters is neither technically or economically viable. Similarly whilst refurbishment of current and voltage transformers is technically possible, in reality, its success would be doubtful and the refurbishment works would be prohibitively expensive.

The balance of the assets within the AIS asset class are suitable for varying degrees of refurbishment depending upon the availability of suitable replacement components and the skill sets necessary for the works. Due to their simple construction, refurbishment of isolators and earthing switches would be relatively straightforward whereas refurbishment of circuit breaker interrupters would be far more complex.

Refurbishment decisions are made for each asset type on the basis of economic viability and likelihood of success

6.3.1.2 Replacement

Asset replacement would typically be on a “like for like” basis. However opportunities to mitigate the fire and explosion risks inherent to oil/paper insulation systems would be explored through means such as the use of alternative design instrument transformers and replacement of oil type circuit breakers with SF6 type.

In addition the use of dead tank type circuit breakers where the current transformers are installed outside the earthed bushing turrets would allow the free standing oil filled post type current transformers to be removed.

6.4 Asset Disposal Plan

Retired assets are assessed for disposal or recovery under the ActewAGL procedure PR5017, "Recovery and Disposal of Reclaimed Network Assets".

Those assets containing PCB contaminated oil will be disposed of in accordance with the ActewAGL manual SM4606, "Environmental PCB Management Plan".

6.5 Associated Asset Management Plans

This section outlines related asset classes which are considered in this ASP. Planning and alignment with associated asset classes is important to provide the best technical and economic option which may integrate with other asset classes.

6.5.1 Power Transformer Assembly

The asset management plan for Power Transformer Assembly assets is considered in this plan to optimise network maintenance by alignment of maintenance activities with common outages.

6.6 Asset Strategy Optimisation Plan

The asset strategy optimisation plan lists initiatives and future improvement opportunities to improve the management of this asset class. This includes:

- Enhanced condition monitoring of circuit breakers through on-line monitoring of load and fault switching duty;
- Opportunity based replacement of live tank circuit breakers and separate post type current transformers with dead tank circuit breakers with integrated (non high voltage) current transformers;
- The use of alternative construction type voltage and current transformers such as, non-oil filled types;
- Replacement of silicon carbide type, gapped surge arresters with zinc oxide type, non-gapped units;
- The installation of isolated type earth connections for surge diverters to allow on line monitoring of leakage current;

7 Program of Work

This section provides the program of work and the resulting operational and capital expenditure forecasts.

7.1 Maintenance Program

This section outlines the operational expenditure for planned maintenance, unplanned maintenance and condition monitoring.

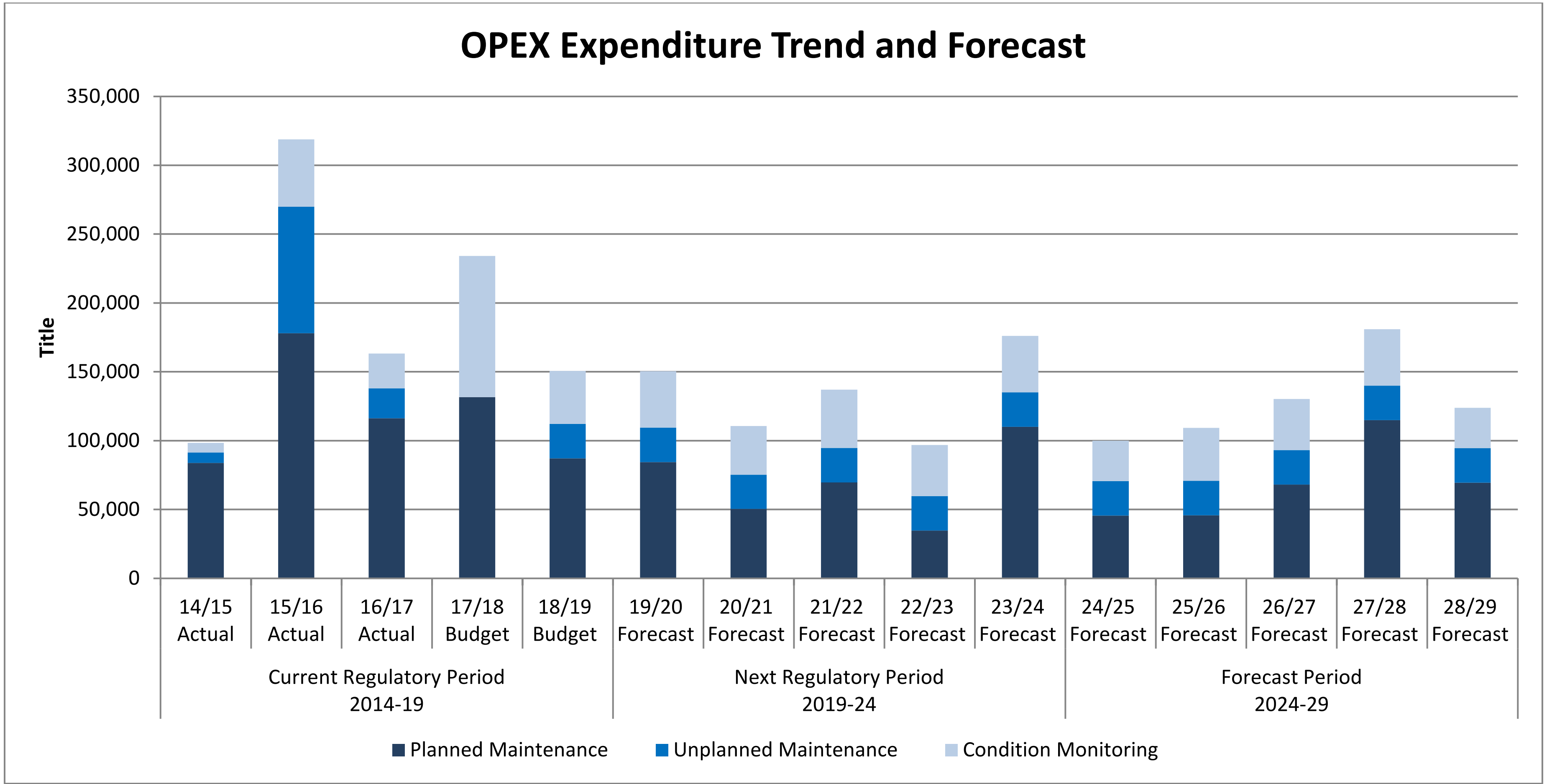

Figure 11: OPEX for Maintenance Program - AIS Assets

7.2 Capital Program

This section outlines the capital expenditure for asset replacement and refurbishment.

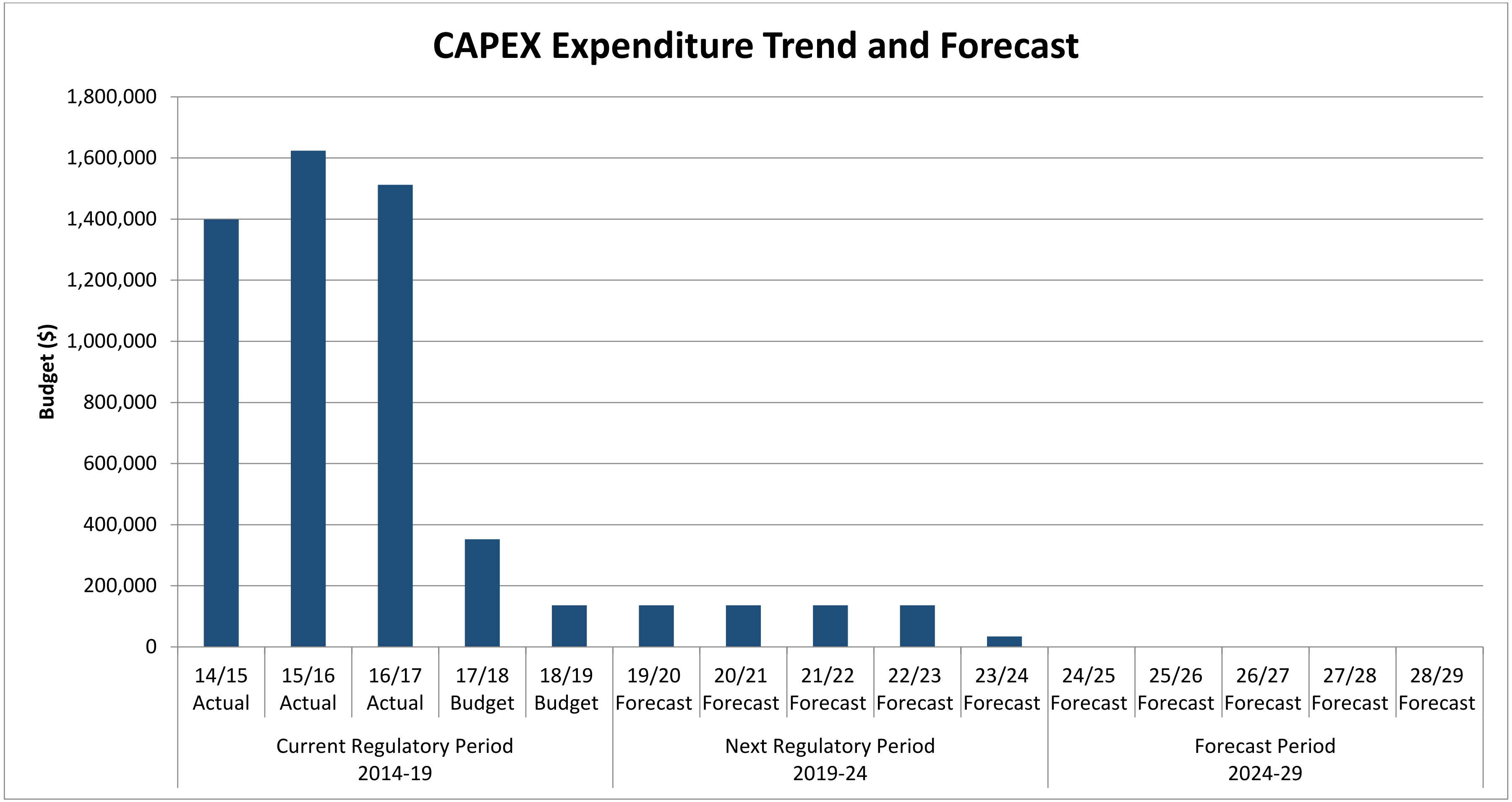

Figure 12: CAPEX Program - AIS Assets

7.3 Budget Forecast

This section provides a 10 year forecast for the CAPEX & OPEX budgets.

Total Budget	2018/19	2019/20	2020/21	2021/22	2022/23	2023/24	2024/25	2025/26	2026/27	2027/28	2028/29
CAPEX	**136,000**	**136,000**	**136,000**	**136,000**	**136,000**	**34,000**	**0**	**0**	**0**	**0**	**0**
OPEX	**150,676**	**150,416**	**110,567**	**136,992**	**96,909**	**176,172**	**99,938**	**109,236**	**130,299**	**180,942**	**123,788**
Planned Maintenance	87,257	84,393	50,403	69,667	34,792	110,149	45,633	45,817	68,182	114,919	69,483
Unplanned Maintenance	25,010	25,010	25,010	25,010	25,010	25,010	25,010	25,010	25,010	25,010	25,010
Condition Monitoring	38,409	41,013	35,154	42,315	37,107	41,013	29,295	38,409	37,107	41,013	29,295

Table 18: AIS Assets CAPEX & OPEX Budget Forecast Summary

The replacement projects are justified through Project Justification Report(s).

7.4 Program of Work Summary

The program of work for summary for 2018-24 is shown in Table 19.

Year	2018/19		2019/20		2020/21
Tasks	**Units**	**Budget ($)**	**Units**	**Budget ($)**	**Units**
CAPEX	**4**	**136,000**	**4**	**136,000**	**4**
Refurbishment	**4**	**136,000**	**4**	**136,000**	**4**
Refurbish 132kV/66kV Circuit Breaker	4	136,000	4	136,000	4
OPEX	**117**	**150,676**	**122**	**150,416**	**111**
Planned Maintenance	**54**	**87,257**	**55**	**84,393**	**53**
Maintain 132kV/66kV AIS Earth Switch Maintenance	8	1,432	8	1,432	10
Maintain 132kV/66kV AIS Isolator Maintenance	35	33,355	37	35,261	41
Maintain 132kV/66kV Circuit Breaker	11	52,470	10	47,700	2
Unplanned Maintenance	**4**	**25,010**	**4**	**25,010**	**4**
Repair 132kV - 66kV Circuit Breaker	1	5,000	1	5,000	1
Top-up Circuit Breaker SF6 Gas	2	4,050	2	4,050	2
SF6 Gas leak repairs	1	15,960	1	15,960	1
Condition Monitoring	**59**	**38,409**	**63**	**41,013**	**54**
Test 132kV-66kV CT Oil	39	25,389	43	27,993	30
Test 132kV-66kV VT Oil	20	13,020	20	13,020	24
Grand Total	**121**	**286,676**	**126**	**286,416**	**115**

Table 19: AIS Assets Capital Program of Works

Appendix A Maintenance Plan Details

Appendix A provides additional details of the data used in evaluation of the asset management strategy options, including the costing and budget forecasting.

Appendix A.1 Asset Management Tasks Unit Costs

Unit costs for this asset class have been estimated and are summarised below.

A.1.1 Planned Maintenance Tasks

Asset Type	Task	Unit Cost ($)
132kV & 66kV Earth Switch	Maintain 132kV/66kV AIS Earth Switch Maintenance	179
132kV & 66kV Isolator	Maintain 132kV/66kV AIS Isolator Maintenance	953
Oil-filled Circuit Breaker	Maintain 132kV/66kV Circuit Breaker –class 1	4,770
SF6 Dead Tank Circuit Breaker	Maintain 132kV/66kV Circuit Breaker –class 1	4,770
SF6 Live Tank Circuit Breaker	Maintain 132kV/66kV Circuit Breaker –class 1	4,770

Table 20: Planned Maintenance Task Unit Costs

A.1.2 Unplanned Maintenance Tasks

Asset Type	Task	Unit Cost ($)
132kV Circuit Breakers	Repair 132kV - 66kV Circuit Breaker	5,000
SF6 Live Tank Circuit Breakers	Top-up Circuit Breaker SF6 Gas	2,025
SF6 Live Tank Circuit Breakers	SF6 Gas leak repairs	15,960

Table 21: Unplanned Maintenance Task Unit Costs

A.1.3 Condition Monitoring Tasks

Asset Type	Task	Unit Cost ($)
132kV & 66kV Current Transformer	Test 132kV-66kV CT Oil	651
132kV & 66kV Voltage Transformer	Test 132kV-66kV VT Oil	651

Table 22: Condition Monitoring Task Unit Costs

A.1.4 Replacement and Refurbishment Tasks

Asset Type	Task	Unit Cost ($)
132kV & 66kV Isolator	Replace 132kV & 66kV Isolator	24,141
Oil-filled Circuit Breakers	Replace Oil-filled circuit breaker	133,094
	Refurbish Oil-filled circuit breaker	34,000
SF6 Dead Tank Circuit Breakers	Replace SF6 Dead Tank Circuit Breaker	255,950
	Refurbish SF6 Dead Tank Circuit Breaker	34,000
SF6 Live Tank Circuit Breakers	Replace SF6 Live Tank Circuit Breaker	133,094
	Refurbish SF6 Live Tank Circuit Breaker	34,000
132kV & 66kV Current Transformer	Replace 132kV-66kV CT	18,929
132kV & 66kV Voltage Transformer	Replace 132kV-66kV VT	18,929

Table 23: Replacement and Refurbishment Task Unit Costs

Appendix B Risk Definitions

Appendix B provides reference information detailing how the severity of an effect, the probability of failure and the likelihood of detection are defined and ranked for the analysis of risk.

B.1 Severity

Effect	SEVERITY of Effect	Ranking
Catastrophic	Hazardous-without warning. Very high severity ranking, potential failure mode affects safety, noncompliance with policy and without warning.	10
Extreme	Hazardous-with warning. Very high severity ranking, potential failure mode affects safety, noncompliance with policy with warning.	9
Very High	Item inoperable, with loss of primary function	8
High	Item operable, but primary function at reduced level of performance	7
Moderate	Equipment operable, but with some functions inhibited	6
Low	Operable at reduced level of performance	5
Very Low	Does not conform. Defect obvious.	4
Minor	Defect noticed by routine inspection	3
Very Minor	Defect noticed by close inspection	2
None	No effect	1

B.2 Occurrence

PROBABILITY of Failure	Failure Probability	Failure rate Lamda "λ"	Ranking
Very High: Failure is almost inevitable	Very High: Failure is almost inevitable. Possible Failure Rate >= 1 every week.	0.1429	10
	Very High: Failure is almost inevitable. Possible Failure Rate >= 1 every month.	0.0333	9
High: Repeated failures	High: Repeated failures. Possible Failure Rate >= 1 every 3 months.	0.0111	8
	High: Repeated failures. Possible Failure Rate >= 1 every 6 months.	0.0056	7
Moderate: Occasional failures	Moderate: Occasional failures. Possible Failure Rate >= 1 every year.	0.0027	6
	Moderate: Occasional failures. Possible Failure Rate >= 1 every 3 years.	0.0009	5
	Moderate: Occasional failures. Possible Failure Rate >= 1 every 5 years.	0.0005	4
Low: Relatively few failures	Low: Relatively few failures. Possible Failure Rate >= 1 every 8 years.	0.0003	3
	Low: Relatively few failures. Possible Failure Rate >= 1 every 15 years.	0.0002	2
Remote: Failure is unlikely	Remote: Failure is unlikely. Possible Failure Rate >= 1 every 20 years.	0.0001	1

B.3 Detection

Detection	Likelihood of DETECTION	Ranking
Absolute Uncertainty	Control cannot prevent / detect potential cause/mechanism and subsequent failure mode	10
Very Remote	Very remote chance the control will prevent / detect potential cause/mechanism and subsequent failure mode	9
Remote	Remote chance the control will prevent / detect potential cause/mechanism and subsequent failure mode	8
Very Low	Very low chance the control will prevent / detect potential cause/mechanism and subsequent failure mode	7
Low	Low chance the control will prevent / detect potential cause/mechanism and subsequent failure mode	6
Moderate	Moderate chance the control will prevent / detect potential cause/mechanism and subsequent failure mode	5
Moderately High	Moderately High chance the control will prevent / detect potential cause/mechanism and subsequent failure mode	4
High	High chance the control will prevent / detect potential cause/mechanism and subsequent failure mode	3
Very High	Very high chance the control will prevent / detect potential cause/mechanism and subsequent failure mode	2
Almost Certain	Control will prevent / detect potential cause/mechanism and subsequent failure mode	1

Appendix C Cost Estimate

Appendix B provides the cost estimate for the replacement of 66kV switchgear at Fyshwick Zone Substation.

Preliminary Estimate ± 30% Accuracy					
Description	**Notes**	**Unit**	**$/Unit**	**Quantity**	**Cost**
Replace 66kV Primary Assets					$ 1,700,000
66kV circuit breakers	Allowance	ea	$ 100,000	5	$ 500,000
66kV Voltage Transformers	Allowance	ea	$ 50,000	2	$ 100,000
66kV Isolators	Allowance	ea	$ 50,000	5	$ 250,000
66kV Current Transformers	Allowance	ea	$ 50,000	5	$ 250,000
66kV post insulators and misc hardware		lot	$ 100,000	1	$ 100,000
Labour and plant	Allowance	lot	$ 500,000	1	$ 500,000
Project Subtotal without overheads					**$ 1,700,000**
Overheads	Corporate overheads				$ 680,000
Project Sub Total with overheads					$ 2,380,000
Contingency					$ 357,000
All project works	Preliminary allowance		$ 0		$ 357,000
Project total with overheads and contingency					**$ 2,737,000**