Appendix 5.15: Primary assets – HV underground cables 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.

evoenergy

ASSET SPECIFIC PLAN

Primary Assets

High Voltage Underground Cables

Document Number: SM1128

Version Control

Date	Version	Description	Author	Reviewed
06/06/17	0.1	Initial Draft		
22/09/2017	2.0	Version for approval		
03/10/2017	3.0	Review		
31/10/2017	4.0	Review – Cost review and general updates due to top down risk-cost challenge.		
06/11/2017	5.0	Sternberg and ANU Backup feeder replacement budget/cost rectifications		

Approval

Author	**Primary Assets Engineer**	31/10/2017 Name Date
Endorsed	**Primary Assets Manager**	01/11/2017 Name Date
	Branch Manager Asset and Network Performance	3/11/2017 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

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Glossary

Term	Definition
AAD	ActewAGL Distribution
AEMC	Australia Energy Market Commission
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
ASP	Asset Specific Plan
CAPEX	Capital Expenditure
CB	Circuit Breaker
FMEA	Failure Mode and Effects Analysis
HV	High Voltage
kV	Kilovolt
LV	Low Voltage
MTBF	Mean Time Between Failures
NER	National Electricity Rules
NSP	Network Service Providers
OEM	Original Equipment Manufacturer
OPEX	Operational Expenditure
FPI	Fault Passage Indicator
PoF	Probability of Failure
PoW	Program of Work
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
STPIS	Service Target Performance Incentive Scheme

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 complies with ISO 6.2.2 planning to achieve asset management objectives. Figure 1 shows the alignment of ASPs in the asset management system.

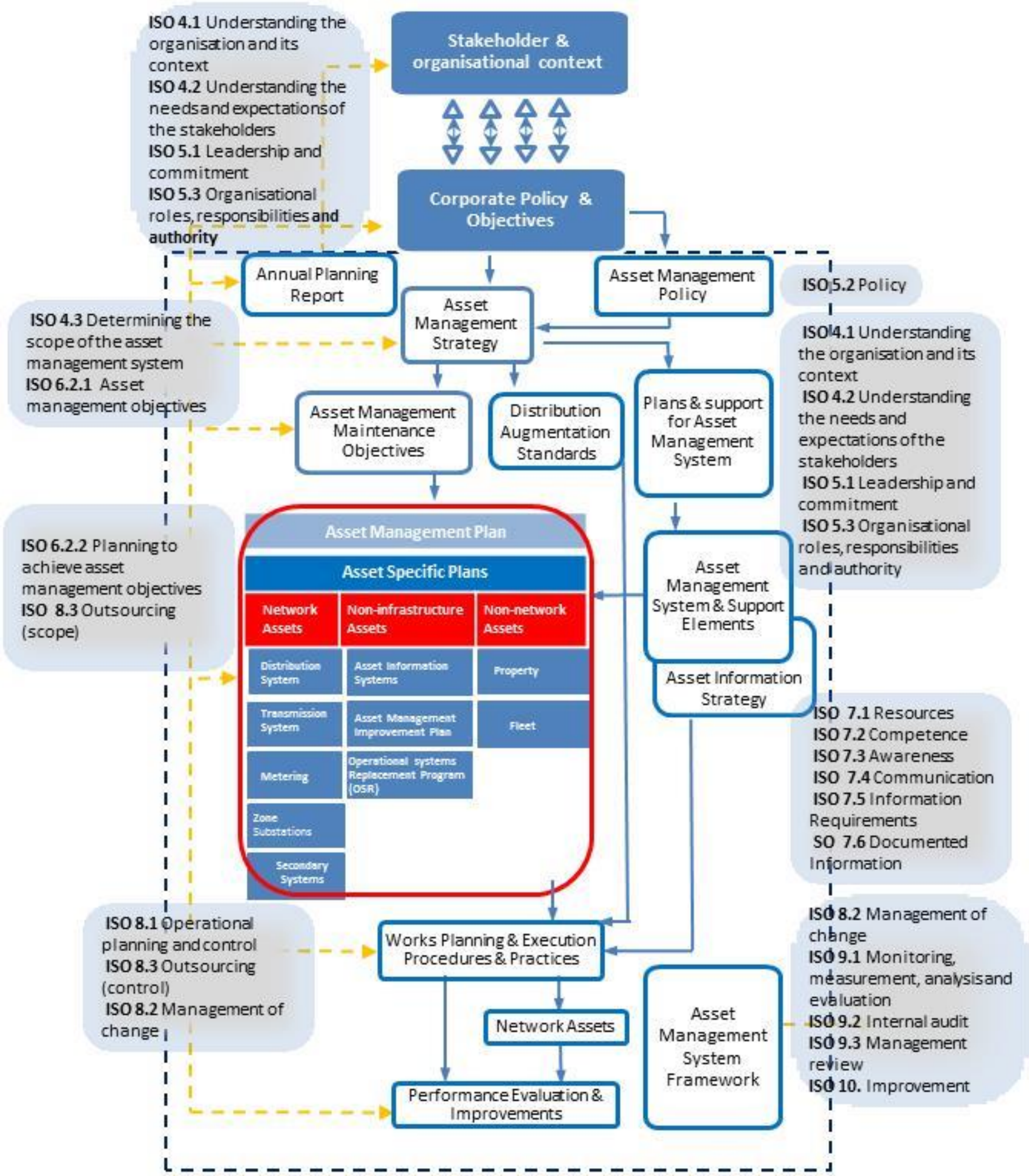

Figure 1: Asset management system structure

1 Executive Summary

Cables are insulated conductors, normally installed underground to transmit electricity for high voltage (HV), low voltage (LV) mains and services. Since the 1980s, all new sub-division development in Australian Capital Territory (ACT) is reticulated with underground distribution network. The underground cable asset is managed and categorised by the voltage level, insulation type and the type of cable construction.

This ASP adopts a risk-condition based approach, in accordance with ActewAGL strategic direction, to determine the optimal strategy to maintain and replace underground high voltage cables and accessories over their lifetime. This approach is designed to ensure that the assets are replaced based on their condition and risk (calculated and measured) rather than age alone.

Accordingly, the health of various HV underground cables were determined as a starting point, followed by risk-condition based scenario planning analysis for the 2019-2024 regulatory period to choose the most viable option from:

- Option 0: Reactive Strategy. This strategy was analysed in order to understand and gauge the baseline risk of this asset class with only reactive repairs (cable fault rectification) work undertaken.
- Option 1: Existing Strategy. The existing strategy is predominantly a reactive approach; no asset health monitoring or systematic replacement program is employed. Assets are replaced when they fail or are deemed as being too unreliable to continue in service.
- Option 2: Aged Based Replacement (ABR). An age based replacement strategy will see feeders being replaced once they are of a certain age, dictated by the construction of the cable (paper or XLPE insulation). Cables within the ActewAGL network have been shown to have a strong correlation between age and probability of failure, therefore this strategy was considered.
- Option 3: Condition Based Monitoring (CBM). A condition based monitoring approach is considered by industry to be the most efficient method of asset management in terms of asset lifecycle utilisation. This strategy would see at-risk feeders being subject to engineering tests to determine actual health and risk, and replaced once certain thresholds are met. The main benefit with this strategy is that healthy feeders are left in-service for longer, and at-risk feeders are replaced sooner, irrespective of the theoretical design service life.

Based on the risk-condition approach, cost optimisation benefit, and the health of the assets, this plan recommends Option 3 as the strategy that provides the lowest risk and greatest financial benefits. The optimised program of work budget for CAPEX and OPEX is presented in Table 1.

Total Budget[1]	2018/19	2019/20	2020/21	2021/22	2022/23	2023/24
CAPEX	$4,066,419	$2,878,633	$3,245,463	$1,889,317	$2,448,062	$5,724,597
OPEX	$812,311	$812,311	$812,311	$812,311	$866,311	$758,311
Planned Maintenance	$0	$0	$0	$0	$0	$0
Unplanned Maintenance	$380,311	$380,311	$380,311	$380,311	$380,311	$380,311
Condition Monitoring	$432,000	$432,000	$432,000	$432,000	$486,000	$378,000

Table 1: OPEX and CAPEX Optimised Program of Work Budget

[1] Costs were reviewed as part of a top-down risk-cost challenge performed in October 2017 by Cutler Merz.

The adoption of Option 3 is a significant change to the management strategy of underground cables, however due to an ageing population and increasing number of asset failures it is deemed necessary to address the rising risk exposure. As detailed within section 5, the implementation of this strategy will result in a higher risk exposure at the end of the 10 year forecast period as compared to exposure levels in 2017. This is considered acceptable by the business due to cost constraints, comparatively lower levels of risk as compared to other strategy options, as well as due to the underground nature of this asset class reducing overall safety concerns.

The key changes that need to be implemented as a result of a condition based monitoring (Option 3) strategy are:

- Proactive cable condition monitoring; as opposed to reactive condition assessment. This includes:
    - Tier 1 tests – Ongoing desktop analysis of feeder performance
    - Tier 2 tests – tan delta and/or online PD tests
    - Tier 3 tests – Offline partial discharge tests
- High voltage cable termination condition monitoring – partial discharge testing as part of the existing substation inspection program.

Implementation will commence in August 2017, for delivery during the 17/18 FY and beyond.

2 Asset Class Overview

This section provides an overview of the strategy and objectives specific to the asset class covered by this ASP, provides details of the assets included and their function, and explores the needs and opportunities specific to this asset class.

This ASP covers the high voltage underground cable asset class, which fall within the Primary Assets, Distribution Underground portfolio. The principal objective of this asset class is to carry electrical energy at 11kV from zone substations to distribution substations, in order to be stepped down to 400V and ultimately supplied to customers.

For details of the asset groups contained within the high voltage cable asset class, refer to section 2.2.

2.1 Asset Class Objectives

The asset class strategy presented in this ASP 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 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 • Ensure design and acceptance for new assets complies with standards
Reliable	
• Tailor monitoring and replacement programs for each asset based on 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 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 • Improve reliability through UG cable networks planning and design

Asset Management Objectives	Asset Class Objectives
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 • Deliver PoW outlined in this plan
People	
• Proactively seek continual improvement in asset management capability and competencies of maintenance personnel.	• Promote continual improvement

Table 2: Asset Class Objectives

The strategy and ASP must be practical in the sense that it can be implemented, must also be flexible enough to satisfy the future requirements of the ActewAGL network, and must be cost effective and efficient with consideration of both technical and human resources.

2.2 Asset Groups

The following table provides a broad-based classification of asset groups within the asset class.

Asset Class	UG HV Cables
Asset Groups	11kV underground cables 11kV underground joints 11kv cable terminations

Table 3: Asset Classification – HV UG Cable Assets

2.3 Asset Functions

Underground HV cables transmit electric power between two termination points at high voltage.

A cable termination provides insulation to the cable ends up to the point of electrical connection to other equipment such as switchgear, overhead line or transformers.

A cable joint provides continuity of two underground cable sections.

2.3.1 Asset Function Definitions

The majority of high voltage cables are three-core construction, with the conductor material being either stranded aluminium or copper.

Cable types typically fall into two different categories:

- Paper insulated lead covered (PILC) cables
- Polymeric (XLPE or PVC) insulated cables

The function of assets in this asset class are described in the following sub-sections.

2.3.1.1 PILC Cable

Older 11kV cables in the ActewAGL Distribution Network are predominantly PILC cables. PILC cables are paper insulated with a lead metallic sheath covering over the insulation. These cables normally have a steel wire or tape armouring between two layers of bitumen compounded hessian tapes as an over sheath for mechanical protection.

2.3.1.2 XLPE Cable

Since the early 1980s, polymeric cables have been used in the industry and within the ActewAGL distribution network. Polymeric cable insulation is either Polyvinyl Chloride (PVC) or cross-linked polyethylene (XLPE). The XLPE cable type is commonly used for HV cables. The cable metallic sheath or screen is made out of aluminium sheath, lead sheath or copper screen wires. The cable oversheath is made from Polyvinyl Chloride (PVC) and high density polyethylene (HDPE).

2.3.1.3 Cable Terminations

Cable terminations can be classified into the following main categories based on their installation method.

A) Taped and porcelain/cast iron

Older PILC cables have a paper taped stress cone with compound filled porcelain or cast iron as the insulator and finally sealed with a lead plumbing or wipe joint. Due to safety concerns, ActewAGL has replaced all cast iron HV cable terminations (‘potheads’) installed on overhead poles, with heat shrink cable terminations.

B) Heat shrink applied with a blow torch

All new HV and LV outdoor cable terminations are heat shrink type. Heat shrink cable terminations use high permittivity material for stress control.

C) Elbow separable connector, cold shrink and cold applied

Elbow separable connectors have also been installed in ActewAGL since the late 1990s. Elbow separable connectors are used to connect cables to transformer and switchgear.

2.3.1.4 Cable Joints

Because of the limitation of cable drum lengths, joints are required to join two cable sections together. Joints are also required for cable repair and for connecting new substations into a section of existing cable. The principle of underground joints is similar to cable termination. Joint construction consists of a ferrule to connect the two cable conductors; mechanical stress control feature at the screen cut area, insulation to provide the same or better electrical performance as the underground cable, and finally mechanical and environmental protection in the outer jacket or casing.

2.4 Needs and Opportunities

Given that this ASP covers two different main asset groups, the needs and opportunities of each have been discussed separately, as defined below.

2.4.1 Underground Cables and Joints

Needs

The underground HV cable assets have historically been managed on a run-to-fail basis, with little to no condition monitoring activities undertaken and no maintenance programs in place. This has resulted in a large ageing asset base with no reliable historical health data.

From 1991 until the end of 2016 there was an average of 21 faults per year (comprising of cable and joint failures); however, inspecting the frequency of cable faults yearly highlights an increase as time progresses and provides a foundation for the concerns of ActewAGL. If the trend is expanded linearly, by 2025 there will be 30 faults per year and by 2040 there will be 36. This is a result of ageing assets as well as employing a reactive approach to asset management.

Opportunities

Replacement of all aged and deteriorated cables is neither technically or economically viable.

There is opportunity to stem the forecasted bow-wave of feeder replacements and cable faults by applying sound technical engineering practises (in the form of condition monitoring) in order to identify future points of failure. By doing this, we are enabled to transition from a reactive approach to an increasingly strategic based analysis. For example, as opposed to reactively repairing faults as they occur in isolation, an analysis can be undertaken that takes in to consideration all of the cable segment weak-spots and could result in an alternative cheaper option – proactive full or partial feeder replacement.

2.4.2 Terminations

Needs

Similar to underground cables, HV cable terminations have typically been managed on a run-to-fail basis (with the exception of visual inspections resulting from routine pole and substation inspections).

There are approximately 1,100 Hazemeyer units and 3,700 RMU switchgear within AAD’s network, each with a number of HV terminations. The Hazemeyer units are particularly aged and have been previously identified as high-risk assets, due to their tendency to fail. To date there has been no condition monitoring or maintenance programs undertaken specifically on the cable terminations on these assets.

Opportunities

Substations are currently subject to visual inspections every five years, as dictated by maintenance requirements of other assets within these sites. There is opportunity to utilise these existing routine inspections to analysis partial discharge levels of HV terminations. A handheld PD analyser can be used to quickly assess each termination and categorise the level of criticality and feed-in to a prioritised replacement schedule.

2.5 Associated Asset Classes

Associated asset classes are as follows:

2.5.1 Functional Relationships

Underground HV cable assets have functional relationships with the following asset classes:

- Ring Main Units (RMU's);
- HV Switchboard Assembly;
- Distribution Poles;
- Distribution Enclosures.

3 Asset Base

This section provides details of ActewAGL's asset base for assets that are a part of this asset class, including the current age and condition profiles of the assets and the projected asset count.

3.1 Asset Base Summary

3.1.1 Summary and Data Quality

Data Completeness

- All in-service assets are included in the asset database.
- Data quality is low for this asset class, as detailed below.

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

- Asset commissioning, insulation, and construction type are in some cases inaccurate. This accounts for approximately 250 kilometres of the HV UG network (16% of the population).
- Historical high voltage termination data has not been recorded.
- High voltage joint commissioning dates has not been recorded pre 2013.

The following table gives details of ActewAGL's in-service high voltage cable assets as at July 2017.

Asset Type	Quantity	Design Life (yrs)	Average Age (yrs)	Oldest Age (yrs)
High voltage(11kV) cable - PILC	1,112,206 m	70	54.0	89
High voltage(11kV) cable - XLPE	456,795 m	45	31.9	40
High voltage (11kV) joints	9,908 units	45	N/A[2]	N/A
High voltage (11kV) terminations	Termination data only exists for LV			

Table 4: In-service Asset Summary

3.2 Asset Service Life Expectancy

The design life of paper insulated cables (PILC) is 70 years and 45 years for polymeric insulated cable assets. The useful life may be less than or greater than the design life, which can depend on quality of manufacturing, installation, maintenance and operational conditions. Further, the useful life of cable is largely dependent on the presence of joints along the length of the span, as these are generally the point of failure.

3.3 Asset Age Profile

Figure 1 shows the current age profile (utilising age brackets in ten year increments) of the 11kV underground cable population. Note that a cable segment of 40.5 years will fall in to the 50 age bracket.

[2] Data collection for joint age commenced in Aug 2013.

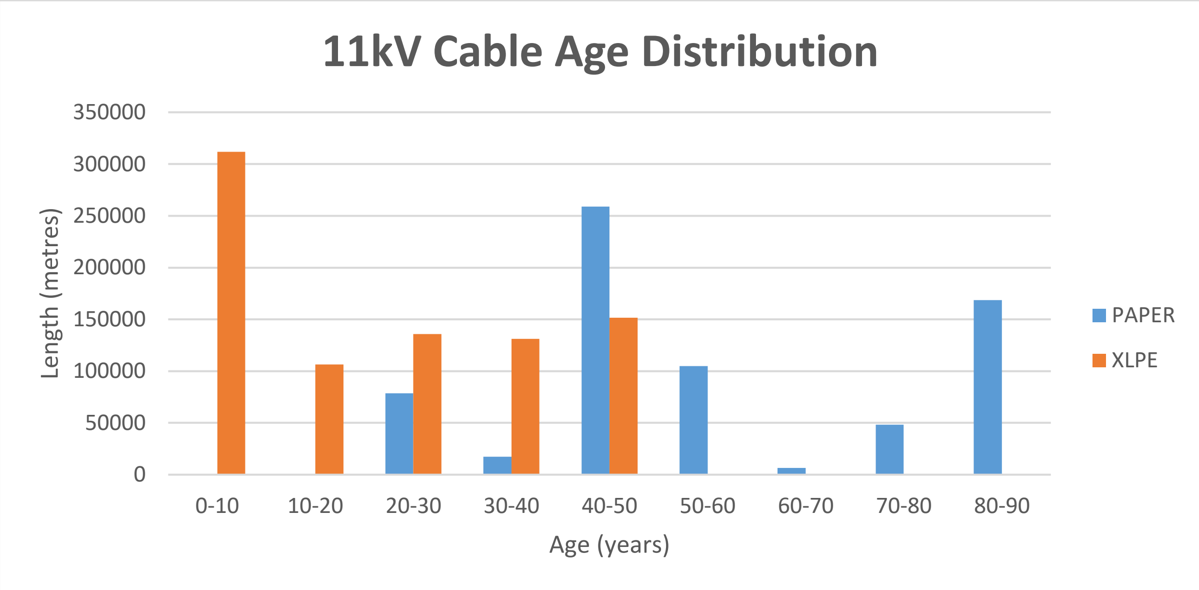

Figure 2: Age Profile of 11kV UG Cables

3.4 Asset Condition Profile

Table 5 gives an indication of the current condition of the 11kV cable assets, amalgamated at the feeder level and sorted by zone substation.

Feeder health ratings were calculated based on feeder age (normalised on length of individual cable sections), total cable fault count, and a metric weighted exponentially based on how recently the cable faults had occurred.

Feeder Score = 0.4 * **Age Score** + 0.2 * **Fault Count Score** + 0.4 * **Fault Date Score**

The overall feeder score was then normalised based on the population of other feeders to produce a score out of 100.

It was found that there was little correlation between the cable insulation type and the expected number of faults, whereas feeder age was a reliable predictor (approximately 1 fault to be expected for every 10 years). Further, there was a strong correlation between joint count and faults experienced, however this was explained with the fact that faults generally result in the introduction of joints, and therefore dilute the reverse causation between the two (i.e. faults cause joints, as opposed to joints causing faults). A count of actual faults experienced was therefore utilised as a more reliable indicator of future faults.

Table 5: Current Feeder Asset Condition

Zone	Feeder	UG Length (metres)	Health Score	Average Health
Belconnen				
	CHANDLER	2960	93	Excellent
	CAMSOUTH	6043	90	Good
	EARDLEY	7158	89	Good
	MARBYNONG	4027	88	Good
	CAENO1-2	5983	88	Good
	AIKMAN	4105	86	Good
	MCGUINESS	9583	85	Good
	BATTYE	7896	85	Good
	CAMNORTH	3315	85	Good

Zone	Feeder	UG Length (metres)	Health Score	Average Health
	EMUBANK	3581	79	Good
	CHAN	3907	78	Good
	BNJMNLAUR	15202	59	Fair
	SWNDNLAMP	18804	54	Fair
	WILLMSLIM	12877	50	Fair
	CHUCULBA	11030	49	Fair
	BLDWNJOYC	14290	48	Fair
	HAYDON	9069	47	Fair
	MCHMBEAN	16805	35	Poor
	SHANNON	8749	31	Poor
City East				
	CNBP2	4152	99	Excellent
	FAIRBAIRN	2061	96	Excellent
	BINARA	5008	95	Excellent
	CHISHOLM	3233	94	Excellent
	EBDEN	3482	88	Good
	MASSON	6188	87	Good
	MACKENZIE	9080	87	Good
	CNSTITUTN	3311	86	Good
	BUNDA	2610	86	Good
	COOYONG	2920	86	Good
	NORTHBRN	4733	86	Good
	AEROPARK	12182	85	Good
	ELECHOUSE	4026	84	Good
	AKUNA	3047	84	Good
	PETRIE	3260	83	Good
	ALLARA	4300	83	Good
	QUICK	4414	82	Good
	DUFFY	5237	81	Good
	AINSLIE	2634	81	Good
	HAIG	5426	81	Good
	IJONG	5764	80	Good
	STOTT	5617	79	Good
	LONSDALE	4333	78	Good
	BRADDON	3656	76	Good
	WAKEFIELD	4477	73	Good
	FERDINAND	7473	60	Good
	COWPER	7450	55	Fair
	WOLSELEY	8376	53	Fair
Civic				
	CHRISTIAN	1734	97	Excellent
	NICHOLSON	3743	96	Excellent
	HOBARTSHRT	4097	94	Excellent
	GIRRAHWN	3712	92	Excellent
	BLACKMTN	4296	91	Excellent
	CSIRO	5008	91	Excellent
	HOBARTLNG	4940	89	Good
	DRYANDRA	3388	87	Good
	JOLIMONT	3543	85	Good
	MCCAUGHEY	4815	84	Good
	BELCWAYNT	4579	75	Good
	WATTLE	5297	68	Good

Zone	Feeder	UG Length (metres)	Health Score	Average Health
	ANUNO12345	23170	60	Good
	BELCWAYSTH	9628	59	Fair
	MILLER	3464	42	Fair
East Lake				
	CESSNOCK	5206	97	Excellent
	LYELL	2697	96	Excellent
	ISA	2929	84	Good
	DAIRYNTH	18682	64	Good
	DAIRYSTH	7916	62	Good
Fyshwick				
	NEWCASTLE	4646	97	Excellent
	AIRPORT	5268	90	Excellent
	WHYLAPLGO	5262	85	Good
	ABATTOIR	5538	79	Good
Gilmore				
	ALDERSON	3421	95	Excellent
	HARMAN1	19204	94	Excellent
	PENTON	5460	93	Excellent
	ROSSMAN	6743	92	Excellent
	FALKINER	8225	91	Excellent
	MAYMAXWL	7320	91	Excellent
	FINDLYSN	10635	87	Good
	JACKIEHOW	10828	87	Good
	EDMOND	8587	87	Good
	MONARO	3200	84	Good
	TRALEE	6482	82	Good
	BEGGS	6546	77	Good
	WILOGHBY	7827	65	Good
Gold Creek				
	BUNBURNG	2034	98	Excellent
	LING	2371	98	Excellent
	GRIBBLE	6041	97	Excellent
	GUNGAHLIN	4646	95	Excellent
	BOULVDNT	3687	95	Excellent
	MAGENTA	13306	95	Excellent
	GURRANG	12637	93	Excellent
	SAUNDERS	15939	92	Excellent
	RILEY	5929	91	Excellent
	LEXCEN	9789	88	Good
	WANGANEE	7089	87	Good
	WESTSTRT	18361	79	Good
	BARRNGTN	12424	77	Good
	HUGHES	9278	76	Good
	FERGUSON	17713	73	Good
	BIRRIGAI	12883	63	Good
	LANDER	15012	55	Fair
	NONA	17132	49	Fair
	ANTHNYRLF	17987	28	Critical
Latham				
	LATHAM	2429	96	Excellent
	HOMANN	3451	95	Excellent

Zone	Feeder	UG Length (metres)	Health Score	Average Health
	POWERS	5165	92	Excellent
	MELBA	2949	91	Excellent
	WEIR	4544	89	Good
	CONLEY	3306	87	Good
	FLOREY	5288	86	Good
	MARKELL	9035	84	Good
	LWMLNGLOE	6994	83	Good
	MACROSSAN	11062	83	Good
	COPLAND	5658	83	Good
	PATERICK	7167	81	Good
	LHOTSKY	13909	79	Good
	TILLYARD	7732	76	Good
	ELKINGTON	8356	75	Good
	LWMLNGLOW	7253	68	Good
	O'LOGHLEN	5078	65	Good
	FIELDER	5072	63	Good
	BOWLEY	9420	62	Good
	SEAL	6147	57	Fair
	VERBRGHN	5374	50	Fair
Telopea Park				
	CNBP1	2844	99	Excellent
	KF1	2544	99	Excellent
	BLACKALL	1733	95	Excellent
	KURRAJONG	3164	93	Excellent
	PRLMTHS4	3389	92	Excellent
	QUEENVICT	3117	92	Excellent
	PRLMTHS1	4144	91	Excellent
	POWERHSE	3270	90	Excellent
	JARDINE	3520	89	Good
	YOUNG	4024	88	Good
	KELLIHER	2464	87	Good
	TELOPKEA	2975	86	Good
	NSW	7090	84	Good
	OVENS	3233	84	Good
	BRISBANE	3888	83	Good
	EDMNDBRTN	5455	82	Good
	STRZLCKI	4904	82	Good
	MONASH	8095	82	Good
	RIVERSIDE	6903	81	Good
	MILDURA	4913	80	Good
	FORSTER	8484	79	Good
	GILES	5998	79	Good
	STURT	5712	74	Good
	EMPIRE	6778	65	Good
	RUSSEL1-2	6829	65	Good
	BOWEN	11541	64	Good
	BROUGHTN	4975	59	Fair
	GALLERY	8456	54	Fair
	THROSBY	5520	53	Fair
	MUNDRUSS3	8039	50	Fair
	CNNINGHM	5827	36	Poor
	ANUBELM	5157	6	Critical

Zone	Feeder	UG Length (metres)	Health Score	Average Health
Theodore				
	TEMPLSTW	6433	95	Excellent
	FAIRLEY	6854	93	Excellent
	EAGLEMONT	10816	91	Excellent
	LAWRCWCK	10790	89	Good
	MORISON	10670	86	Good
	BANYULE	12699	86	Good
	LETHBRIDG	10225	84	Good
	CHPPNDL	12674	76	Good
	CALLISTR	14461	48	Fair
Wanniassa				
	GOUGER	2230	95	Excellent
	FINCHAM	7485	91	Excellent
	HAWKRPRD	4558	90	Good
	GAUNSON	7075	89	Good
	CONOLLY	5498	85	Good
	MURESK	7886	84	Good
	MARCONI	10326	78	Good
	ASHLEY	11409	77	Good
	SAINSBURY	7469	75	Good
	ATHLLON	9081	73	Good
	HEMMINGS	12033	69	Good
	GRIMSHAW	17946	64	Good
	MANNHEIM	8252	63	Good
	MATTHEWS	20723	57	Fair
	BISSHAWK	16237	54	Fair
	SYMERS	5833	52	Fair
	ERINDALE	9183	52	Fair
	STERNBRG	8872	50	Fair
	LONGMORE	12447	42	Fair
	LANGDON	10771	37	Poor
	ROW-PIT	16419	32	Poor
	REID	11799	19	Critical
Woden				
	GARRAN	4410	98	Excellent
	HINDMARSH	2051	98	Excellent
	EASTY	5349	98	Excellent
	DEVONPORT	2021	96	Excellent
	WILSON	2502	96	Excellent
	YAMBA	5701	95	Excellent
	CARRUTHRS	2396	94	Excellent
	PHLIPSTH	3110	92	Excellent
	YARRALUMLA	4039	91	Excellent
	PHLIPNTH	5923	91	Excellent
	STREETON	15982	90	Good
	DEAKINNO1	3681	89	Good
	LAUNCESTN	5349	89	Good
	LYONSWEST	2150	82	Good
	BUNBURY	6864	80	Good
	COOLEMAN	5393	80	Good
	WESTNEAST	7982	79	Good

Zone	Feeder	UG Length (metres)	Health Score	Average Health
	CORINNA	3640	77	Good
	KENT	4016	77	Good
	COTTER11KV	13754	73	Good
	HILDER	12107	65	Good
	KING	5113	65	Good
	MCINNES	4423	64	Good
	THEODORE	7634	64	Good
	FOLINGSBY	8365	46	Fair
	DEAKINNO2	5614	40	Poor
	CURTINNTH	7139	39	Poor

Table 5: Current Feeder Asset Condition

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

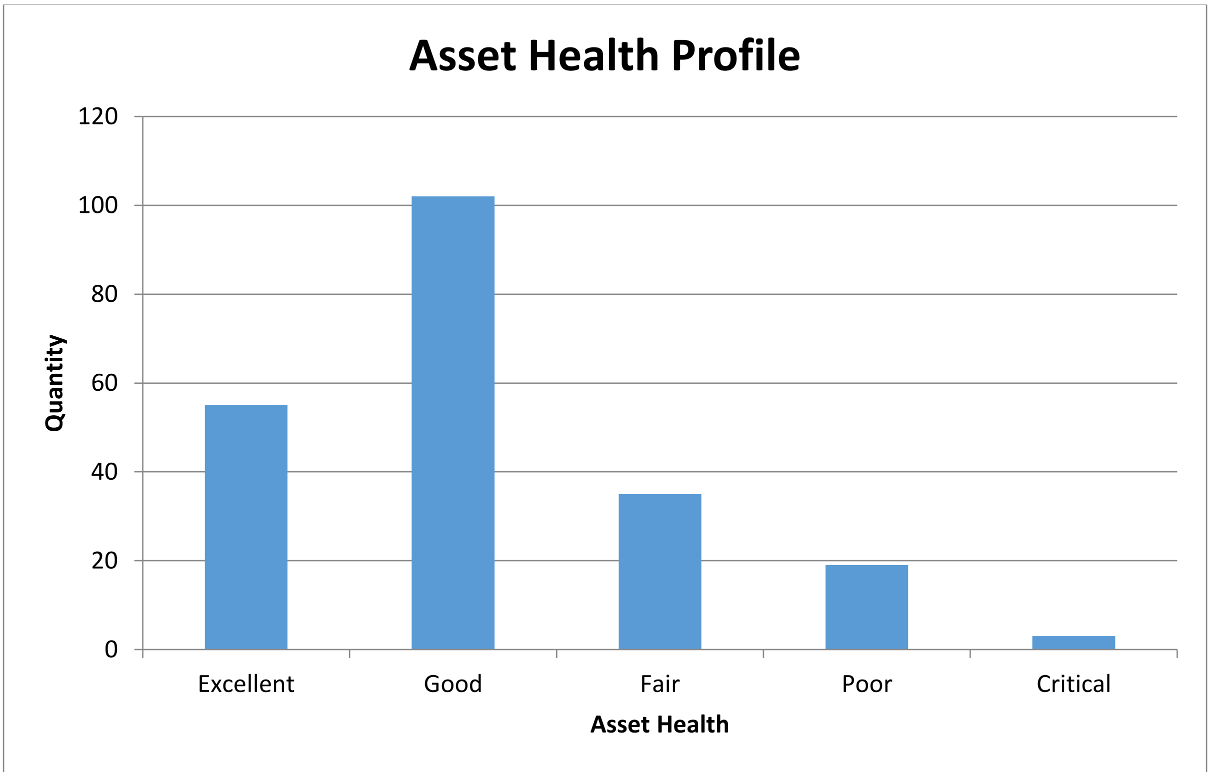

Figure 3: Current Feeder Asset Condition by Feeder Count

Based on the above tables, it can be seen that there are a number of deteriorated cables that will require attention and management.

3.5 Projected Asset Count

The projected asset count is an estimate of the total length of 11kV cable assets in metres by year. A historical average increase of 1.5% has been applied in order to estimate the increase over the next 10 year period. The estimate includes asset additions and retirements through estimated network augmentation and asset retirements over the period. Refer to Figure 3 for details.

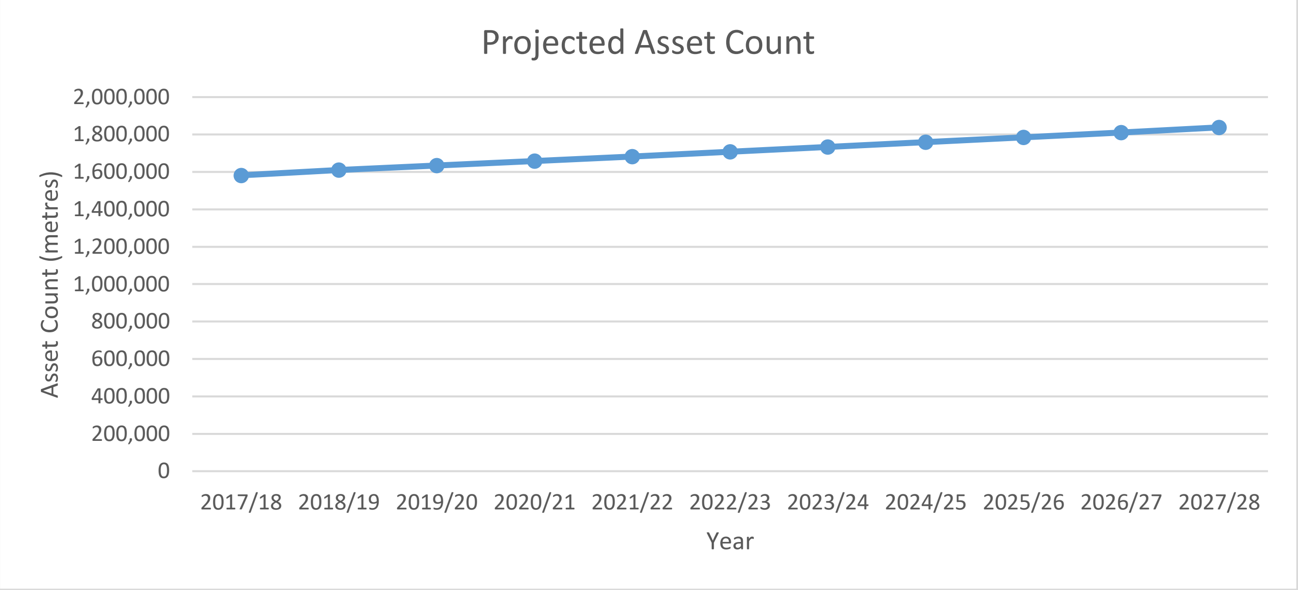

Figure 4: Projected Asset Count of 11kV Cables in Metres

3.5.1 Network Augmentation and Infrastructure Development

The following network augmentation projects affect the asset class population.

3.5.1.1 Project 1 – Gold Creek Zone Substation Feeders

This project entails the construction of two new 11 kV feeders (in addition to one 11 kV feeder already under construction) from Gold Creek Zone Substation to Gungahlin Town Centre East development area to supply additional load growth in East Gungahlin by June 2018. The proposed solution will address two critical load demands listed below.

1. Canberra Metro Traction Power Station forecast to be commissioned by mid-2018.
2. Gungahlin Town Centre East, Gungahlin Cinema, medical centre, East Lake club and other mixed use development load required to be supplied by June 2018.

The proposed two new feeders from Gold Creek are approximately 4.6km and 5.3km in length. The estimated date of completion is June 2018.

3.5.1.2 Project 2 – Gilmore Zone Substation Feeder

This project seeks to construct a new feeder to meet the forecast demand in the industrial suburb of Hume.

The proposed new feeder is approximately 3.0km in length, and is estimated to be commissioned by June 2018.

3.5.1.3 Project 3 – Wanniassa Zone Substation Feeder

This project seeks the construction of a new 11 kV feeder from Wanniassa Zone Substation to Tuggeranong Town Centre. A spare 150mm diameter conduit has been installed as part of the Sternberg feeder replacement project – this spare conduit will be utilised for the proposed new feeder cable.

These works will be carried out during the 2019-24 Regulatory Control Period, with proposed completion by December 2020. The proposed feeder is approximately 4.5km in length.

4 Asset Performance Requirements

This section details the reliability and performance requirements of the high voltage cable 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 will 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 HV underground cables assets by asset type.

The in-service life of a cable is largely dependent on handling practices and workmanship quality of the cable and of the joints. A cable failure is rarely located along a mid-span of cable, rather there is considerably higher probability that the failure will occur on a joint between cable sections.

Generally, underground cables are characterised with an abrupt condition curve, meaning that failures generally cause more failures and eventual complete asset replacement. This is due to the detrimental effects of fault current (and fault-finding current) on the health of a feeder, as well as the increase in number of joints (potential points of failure).

Environmental factors appear to have less effect on this asset class as predominantly they are located below ground, with the exception of terminations.

4.1.2.1 Underground Cables

Deterioration Drivers

- Fault current
- Fault location techniques
- Switching habits
- High loading

Failure Modes

Failure Mode	Failure Cause	Severity	Occurrence	Detection	RPN
Moisture in cable	Ingress during cable storage; Ingress during cable installation; Ingress due to cable fault;	7	7	9	441
Thermal Overload	Incorrect bedding sand resistivity; Inadequate soil resistivity, caused by drought, housing estate water usage changes, or inherent soil characteristics; Incorrect location in trench; Incorrect cable rating; Incorrect rating for transitions between conduits, direct burial, and cable trays; Inadequate protection against thermal variation; Other heat sources not taken in to consideration; Overcurrent during fault; Incorrect protection settings; Increased loading on cable without considering environmental or cable state factors; Cable buried too deep, by either external development, environmental waste, or poor workmanship; Trench backfill not compacted sufficiently, leaving air pockets; Too many cables in trench or conduit.	8	8	9	576
Product quality issue	Manufacture defect	8	8	8	512
Sudden mechanical impact	Third party damage Large tree roots rip up cable when tree falls over Heavy vibration undue external burden on cable crushing trench/overfill	8	6	10	480

Table 6: Common Modes of Failure for UG HV Cables

4.1.2.2 Cable Joints and Terminations

Deterioration Drivers

- Fault current
- Fault location techniques
- High loading
- Switching habits
- Workmanship

Failure Modes

Failure Mode	Failure Cause	Severity	Occurrence	Detection	RPN
Moisture in joint	Ingress due to cable fault; Incorrect process used for cable jointing; Incorrect stripping of cable for jointing; Inadequate shrink-down over cable joint.	6	4	3	72
Thermal Overload	Incorrect bedding sand resistivity; Incorrect location in trench; Inadequate protection against thermal variation; Other heat sources not taken in to consideration; Overcurrent during fault; Incorrect protection settings; Trench backfill not compacted sufficiently, leaving air pockets.	6	9	8	432
High resistance circuit / open circuit	Incorrect crimping; Incorrect instructions / technique; Incorrect shear bolt tightening; Mixed accessory components;	7	4	4	112
Mechanical Damage	Overburden; Compaction too high; Excessive vibration; Stress caused by inadequate design; Stress caused by environmental changes;	9	3	9	243

Table 7: Common Modes of Failure for HV Joints and Terminations

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 asset condition and performance deterioration rates.

4.2.1 Capacity and Capability

Cables are designed to operate at a maximum conductor temperature which will define the cable current rating (Amps).

The cable rating depends on the ability to dissipate heat to the surrounding, based on the following factors:

- Cable construction and material
- Cable dimension
- Cable arrangement
- Installation condition
- Depth of installation
- Ambient temperature
- Initial conductor temperature
- Thermal stabilised backfill and natural soil thermal resistivity
- Surrounding underground services and heat sources

As a part of the design process, the required capacity needs to be confirmed before selecting a sufficient cable size.

While it is possible to operate the cable beyond its thermal limit, it can reduce the life expectancy.

4.2.2 Utilisation

Modern XLPE cables can operate continuously at a maximum conductor temperature of 90°C. However for short periods of time, generally for emergency purposes, an XLPE conductor can operate at up to 130°C. Operating beyond 90°C will cause accelerated insulation degradation and reduce the expected service life.

Belted paper insulated cables can operate at a maximum conductor temperature of 65°C. Screened paper insulated cables can operate at a maximum conductor temperature of 70°C.

High voltage cables are nominally 75% utilised (‘firm’ rating). The remaining 25% is reserved for contingency events where loads can be switched from other feeder circuits during outages.

4.3 Risk and Criticality

This section details the criticality of the HV cable assets in the distribution system and the exposure to risk.

4.3.1 Asset Criticality

Underground cables are critical for power delivery through the connection of equipment or directly to the customer's point of connection. If an underground cable, termination or joint fails, the connected equipment or customer will also lose connection to the electricity distribution network.

The criticality of each cable asset depends on the voltage level and the customer type. Typically, the higher the voltage, the more customers it can potentially affect in an event of a cable fault.

4.3.2 Geographical Criticality

Cable thermal rating is affected by the natural soil property. Geographic location of the cable route, where the natural soil is susceptible to drying out or the natural soil's thermal resistivity is high, can limit the cable thermal rating or result in the cable overheating in instances where it is operated beyond its maximum conductor temperature for prolong period.

The natural soil property should be tested during the design process. Cable route selection or cable sizing must take the results into consideration.

4.3.3 Asset Reliability

Underground cables are designed to be reliable. When installed properly, these assets are designed to be in service for more than 45 years with minimal maintenance.

Assuming that an underground feeder will incur 12 failures during its operational life, the reliability is determined as:

Reliability = (Expected life - downtime) / Expected life = (45 - 12 x 2.5 / 365) / 45 = 99.93%.

5 Asset Management Strategy Options

This section discusses asset class strategies to manage high voltage cable assets throughout their lifecycle and recommends the preferred option. The preferred asset class strategy 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 and Evaluations

Asset class strategies are evaluated against their cost, risk, benefits and consideration of trade-offs between capital and operational expenditure to achieve the asset management objectives. The options that have been considered are:

- Option 0 – Reactive Strategy
- Option 1 – Existing Strategy
- Option 2 – Implementation of age based replacement (ABR)
- Option 3 – Implementation of condition based monitoring (CBM)

5.2.1 Option 0 – Reactive Strategy

This option assesses the inherent risk rating for the high voltage cable asset class if no controls or mitigating strategies are in place.

The Reactive Strategy is to operate assets until failure and restore by performing corrective maintenance (e.g. cable fault repair) or reactive replacement (e.g. termination replacement). As asset condition deteriorates and assets approach the end of their life, the risk exposure of this option rapidly increases.

A risk assessment demonstrating the inherent risks (no controls) highlights risks exposed by this option. This is shown in Table 8.

Likelihood	Option 0 – Inherent Risk Rating				
Almost Certain					
Likely				High 1	
Possible		Medium 2	Medium 4		
Unlikely	Low 1		Medium 1		
Rare	Low 6				
Consequence	Negligible	Minor	Moderate	Major	Severe

Table 8: Risk Assessment – Option 0

The risk profile for this option has been modelled to estimate the risk exposure shown in Figure 5.

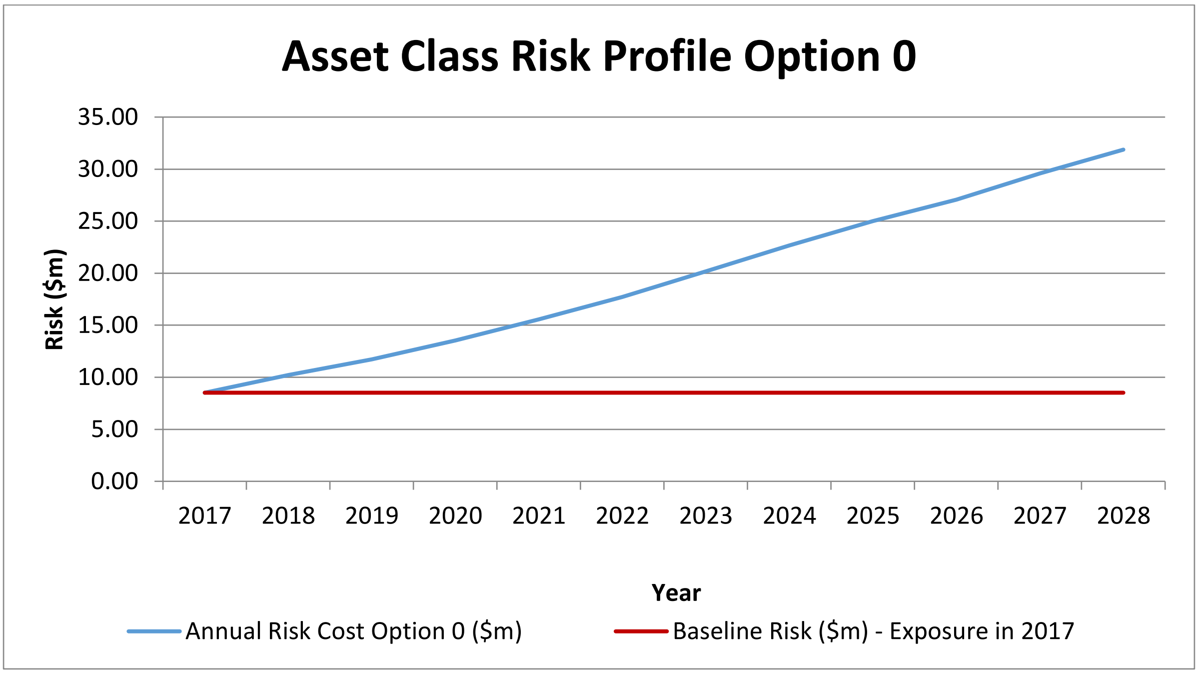

Figure 5: Risk-Cost Analysis – Option 0

The following analysis outlines the outcomes if this option is adopted:

- Operation of critical assets until partial or catastrophic failure;
- Increasing risk exposure due to aging asset population without planned replacement.
- Corrective reactive maintenance to repair faults;

The total CAPEX and OPEX cost for this option is $6,904,378 (2017 – 2029).

5.2.2 Option 1 – Existing Strategy

Similar to option 0, this strategy uses a predominantly reactive approach to quantify individual asset condition and risk. The existing strategy is to operate assets until failure and restore by performing corrective maintenance (e.g. cable fault repair) or reactive replacement (e.g. cable and termination replacement) or minimal proactive replacement (e.g. cable terminations having visible white, brown or black spots or audible partial discharge). As asset condition deteriorates and assets approach the end of their life, the risk exposure of this option rapidly increases.

Feeders are identified for condition assessment and replacement on an ad hoc basis considering recent poor performance (fault) history, generally when the feeder is deemed unsuitable to be left in service carrying load. This approach allows for:

- Replacement of very-high risk assets in critical condition, and
- Low to high risk assets to continue in service.

Currently there is no periodic condition monitoring program or planned replacement program performed for high voltage cables or high voltage cable terminations.

Asset risk is modelled as a function of asset condition, probability of failure and consequence of failure. The approach quantifies asset risk individually based on the assets composition of these parameters, for both high voltage cables and terminations.

This strategy ensures that the minimum level of risk management is performed for this asset class, by including the following tasks:

- Once-off cable condition monitoring on a case-by-case basis of poor performing feeders and associated corrective works (replacement of cable sections);
- Reactive replacement of faulted cable sections, joints, and terminations.

Historically AAD tests and subsequently replaces approximately two feeders per year.

The total CAPEX and OPEX cost for this option is $121,815,552 (2017 – 2029).

The exposed asset class risk ratings for this option are shown in Table 9.

		Option 1 – Current Strategy				
Likelihood	Almost Certain					
	Likely				High 1	
	Possible		Medium 2	Medium 4		
	Unlikely	Low 1		Medium 1		
	Rare	Low 6				
		Negligible	Minor	Moderate	Major	Severe
		Consequence				

Table 9: Risk Assessment – Option 1

The risk profile for this option has been modelled to estimate the risk exposure shown in Figure 6.

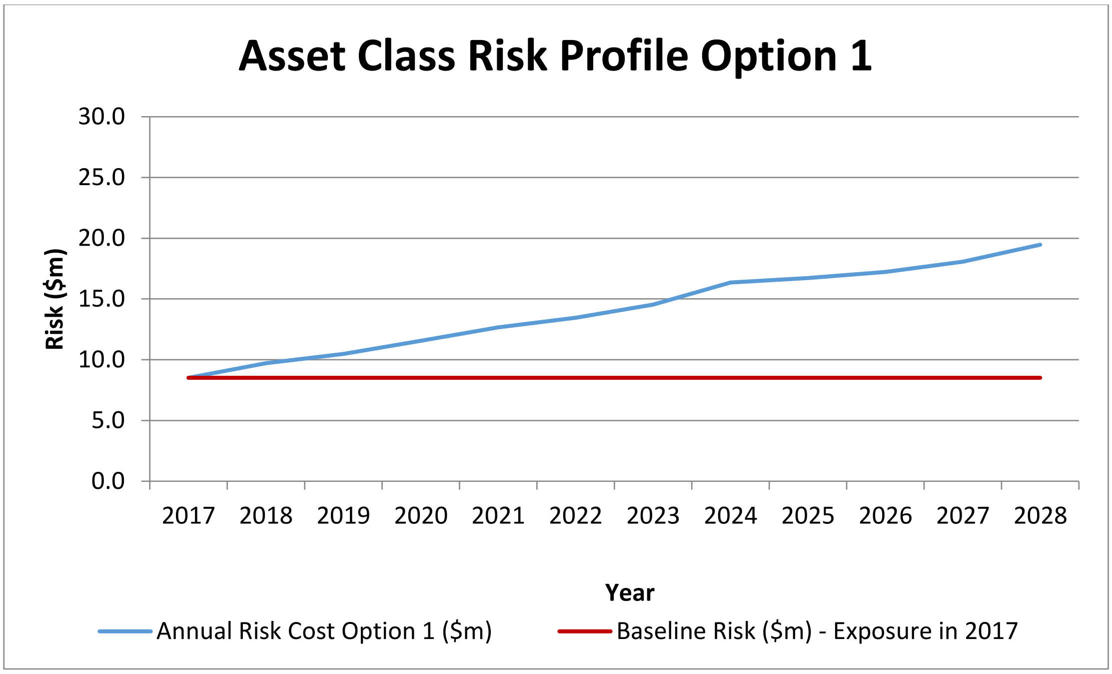

Figure 6: Risk-Cost Analysis – Option 1

The following analysis outlines the outcomes if this option is continued:

- Operation of critical assets until partial or catastrophic failure;
- HV Feeders with only the highest frequency of recent failures tested to obtain asset condition;
- Increasing risk exposure due to aging asset population without planned replacement or condition monitoring program;
- Corrective reactive maintenance to repair faults as they occur.

5.2.3 Option 2 – Age Based replacement

This option implements an aged based replacement (ABR) process that is achieved by an accelerated asset renewal program based on asset age.

The age based replacement option uses the assumption that all assets in the same class deteriorate at the same rate and require replacement at the same age, at end of their design life. The design life of paper insulated lead covered (PILC) cables is 70 years and for modern XLPE cables 45 years.

However, in reality the condition or performance of any two assets of the same make, model, and chronological age, can differ significantly depending on the service conditions such as the normal loading, over loading, number and severity of through faults, fault isolation and location activity etc. Because not all assets deteriorate at a standard uniform rate across the asset class, this strategy has two distinct disadvantages for critical assets. Specifically; assets which deteriorate faster than average are at risk of catastrophic failure before end of their design life, and assets which deteriorate slower than average may be replaced too early.

This option entails utilising field Fault Passage Indicators (FPIs) within the network to reduce fault location time, implementing an accelerated asset renewal program, as well as periodic testing for HV cable terminations. This strategy consists of the following tasks:

- Age based replacement of HV cables and terminations;
- Set and commission of field FPIs;
- Condition monitoring of HV cable terminations, as a part of the current standard substation inspections;
- Reactive replacement of faulted cable sections and terminations.

The total CAPEX and OPEX cost for this option is $278,203,274 (2017 – 2029).

The exposed asset class risk ratings for this option are shown in Table 10.

	Option 2 – Age Based Replacement				
Likelihood					
Almost Certain					
Likely				High 1	
Possible		Medium 2	Medium 4		
Unlikely	Low 2				
Rare	Low 6				
	Negligible	Minor	Moderate	Major	Severe
	Consequence				

Table 10: Risk Assessment – Option 2

The risk profile for this option has been modelled to estimate the risk exposure shown in Figure 7.

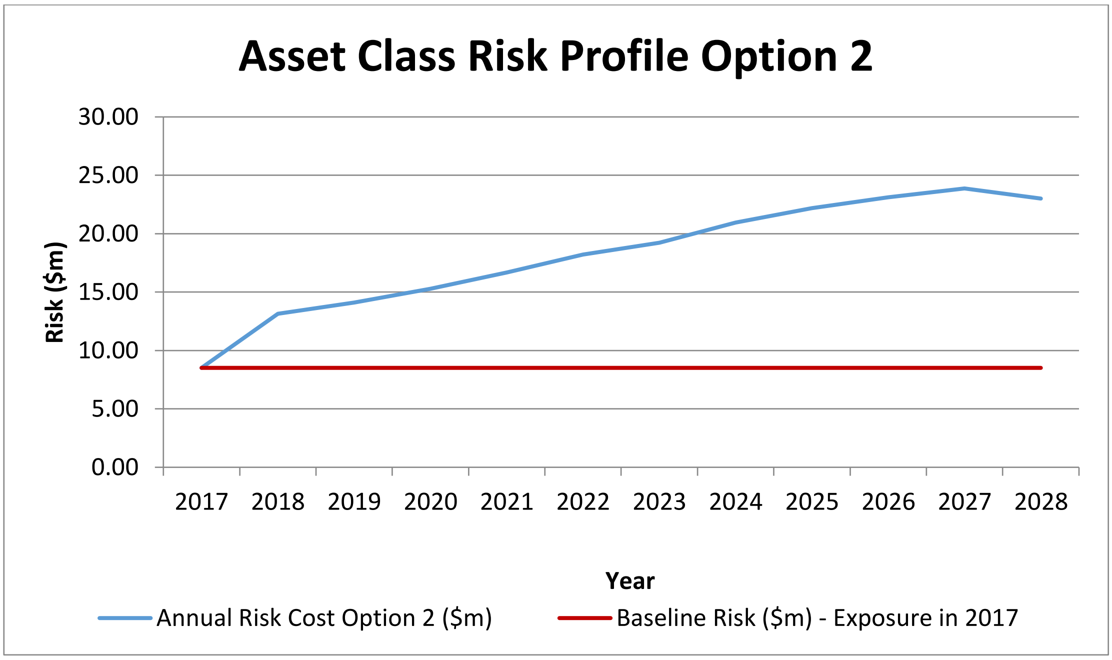

Figure 7: Risk-Cost Analysis – Option 2

The following analysis outlines the outcomes if this option is adopted:

- Planned age based replacement of HV cables and terminations to prevent some instances of catastrophic failure and some partial failures;
- Problematic risk-prone feeders remain in-service until design life is reached;
- Obtaining a health profile of the high voltage terminations within the network;
- Faulted cable segments located efficiently with FPIs, saving on associated unplanned outage costs;
- Corrective reactive maintenance to repair faults as they occur.

Approximately a quarter (135km) of the population of XLPE cable will be simultaneously equalling or exceeding their design life of 45 years by 2025, resulting in a large bow-wave of work at this time. Similarly, 100km of paper insulated cable would be due for replacement in 2017, and approximately another 50km within the following five years.

5.2.4 Option 3 – Condition based monitoring (Preferred strategy)

This option aims to stem the increasing risk associated with the current strategy, as well as reduce the risk as compared to historic levels. This is achieved by implementing a condition based monitoring (CBM) process that assigns health scores to all underground high voltage cables and terminations. The significant difference with this option compared to the current strategy is the identification, rectification, and potential replacement of assets before they fail.

The condition or performance of any two assets of the same make, model, and chronological age, can differ significantly due to the fact that not all assets deteriorate at a standard uniform rate. It is for this reason that condition based monitoring is considered to offer two main advantages over time based monitoring or aged based replacement. Specifically, CBM can prolong the in-service time of a healthy asset, and replace an asset at the optimum point in time before occurrence of in service failure which may have far reaching adverse consequences and higher cost implications.

This option optimises CAPEX and OPEX expenditure while managing the risk exposure for this asset class. This is achieved by utilising FPIs within the network to reduce fault location time, implementing a tiered condition monitoring program for at-risk feeders, as well as periodic testing for HV cable terminations. This strategy consists of the following tasks:

- Tier 1 - Preliminary desktop identification of at-risk HV feeders based on age, fault history, and a metric determined by the date-spread of the fault history;
- Tier 2 tests: for feeders identified from above desktop analysis. Testing comprising of tan-delta analysis and/or online PD analysis (case by case based),
- Tier 3 tests: For feeders that have failed Tier 2 health score requirements. Testing comprising of offline partial discharge (OWTS) analysis;
- Condition monitoring of HV cable terminations, as a part of the current standard substation inspections;
- Set and commission of field FPIs;
- Reactive replacement of faulted cable sections and terminations.

The total CAPEX and OPEX cost for this option is $115,420,359 (2017 – 2029).

The exposed asset class risk ratings for this option are shown in Table 11.

Likelihood	Option 3 – Condition Based Monitoring				
Almost Certain					
Likely					
Possible		Medium 2	Medium 4	High 1	
Unlikely	Low 1		Medium 1		
Rare	Low 6				
Consequence	Negligible	Minor	Moderate	Major	Severe

Table 11: Risk Assessment – Option 3

The risk profile for this option has been modelled to estimate the risk exposure shown in Figure 8.

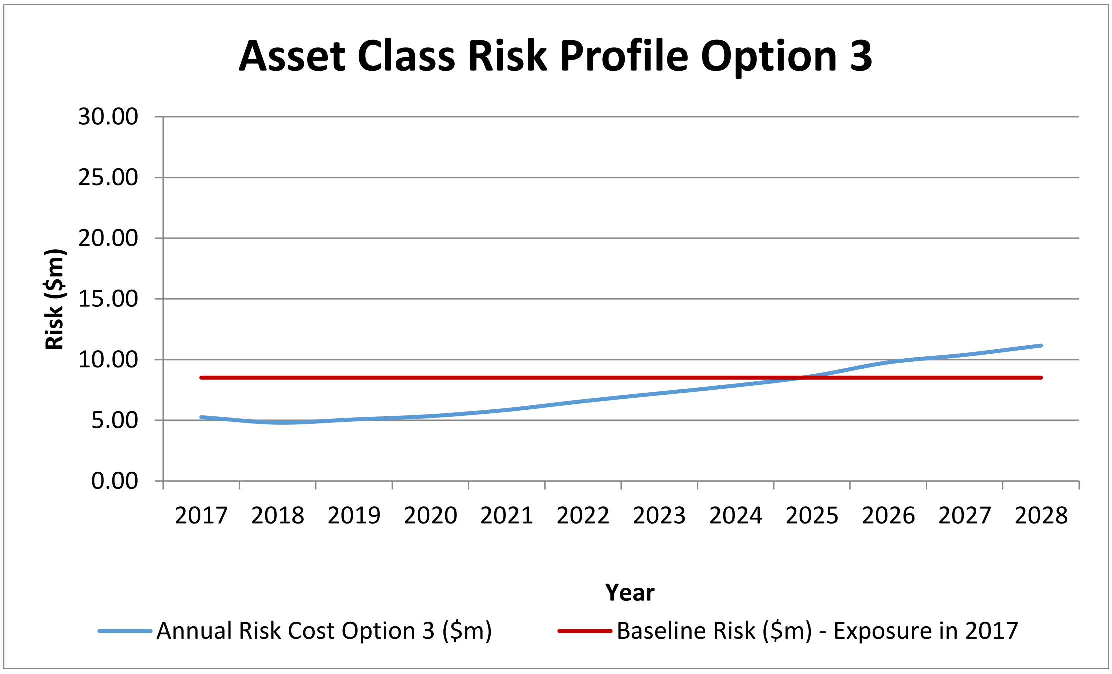

Figure 8: Risk-Cost Analysis – Option 3

The following analysis outlines the outcomes if this option is adopted:

- Planned condition based replacement of HV cables and terminations to prevent catastrophic failure and minimise partial failures;
- Manage risk exposure with planned condition based replacement;
- Obtaining a complete picture of the health profile of the high voltage termination and cable network;
- Faulted cable segments located efficiently with FPIs, saving on associated unplanned outage costs;
- Corrective reactive maintenance to repair faults as they occur.

5.3 Option Evaluation

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

In order to assess the most optimal high voltage cable asset management strategy, a condition and Risk-Cost based modelling approach has been conducted using the RIVA Asset Management modelling tool for the various scenarios.

5.3.1 Financial Evaluation

Financial comparison of technically feasible and acceptable risk options are summarised in Table 12. This summary includes forecast budget CAPEX and OPEX for the period 2018-24 and for comparison the estimated risk exposure.

Option	TOTEX Budget ($) 2018-24	CAPEX Budget ($) 2018-24	OPEX Budget ($) 2018-24	Annual Residual Exposure ($) 2028/29	Annual Risk Reduction ($) 2028/29
Option 0 – Reactive	3,186,636	904,770	2,281,866	31,871,116	0.00
Option 1 – Existing	24,743,938	22,462,072	2,281,866	19,467,037	12,404,079
Option 2 – Age based replacement	61,279,704	58,997,838	2,281,866	22,998,216	8,872,900
Option 3 – Condition based replacement	25,126,357	20,252,491	4,873,866	11,711,294	20,159,822

Table 12: Strategy Cost and Risk Comparison

5.3.2 Asset Strategy Risk Comparison

Figure 9 provides a comparison of the risk exposure with each strategy implementation.

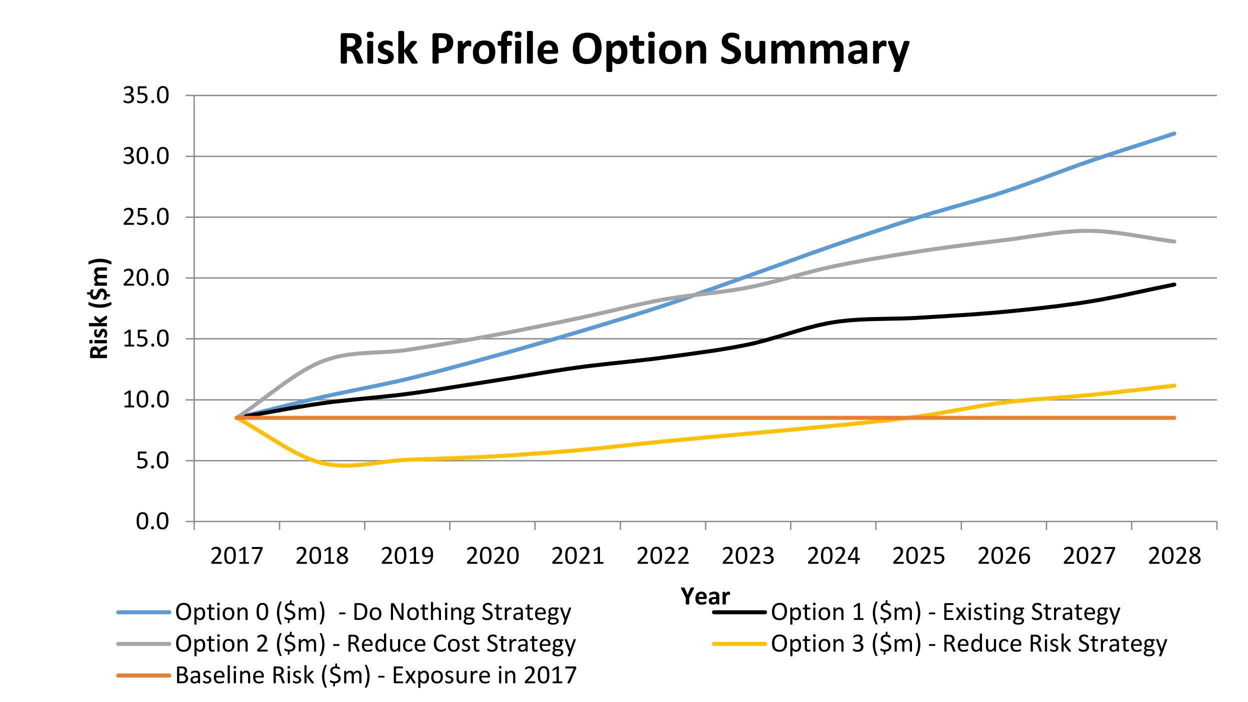

Figure 9: Risk-Cost Analysis – All Options

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 13: Option Evaluation Scoring Criteria

	Criteria				Option Score
	Cost	Risk	Strategic Objectives	Innovation/ Benefits	
Criteria Weighting	**30%**	**30%**	**30%**	**10%**	**100%**
Option 0 – Reactive Strategy	3	1	1	0	50%
Option 1 – Existing Strategy	3	1	1	0	50%
Option 2 – Age based replacement	2	1	1	1	43%
Option 3 – Condition based replacement	2	3	3	3	90%

Table 14: Scoring Matrix

Scoring Key			
0	Fatal flaw	1	Unattractive
2	Acceptable	3	Attractive

Table 15: Scoring key

5.4 Recommended Option

5.4.1 Recommendation

A risk condition based costing approach has been adopted to determine the optimal recommendation for capital replacement projects and maintenance strategy that will provide the best technical and commercial benefit to AAD and its customers.

This approach is expected to improve the SAIFI/SAIDI figures and improve the STPIS benefits. Based on the evaluation of different scenarios for CAPEX and OPEX in section 5.3, the option that will provide the greatest benefit is given below.

Option 3 – Condition Based Monitoring.

This option is the recommended asset management strategy for underground high voltage cables, in order to enable maximum economical asset life while managing business risk, network reliability, and safety. The increase in CAPEX and OPEX costs associated with the implementation of condition based monitoring activities is considered to be justified given the existing asset risk profile and increasing maintenance needs of an aging asset base.

Further, this option enables AAD to harness new capabilities offered by the ADMS in the field of network optimisation. Specifically, the ADMS can offer probabilistic asset failure analysis and dynamic at-risk feeder management (such as lowering loads and thus risk exposure of these identified feeders).

5.4.2 Forecast Asset Condition

Health profile is determined by asset condition and performance history. Condition is determined by the asset's reliability, age, and capacity to meet requirements.

The future health profile is the asset health profile at the end of the Regulatory Period, 2024. This forecast is based on;

- Implementation of the preferred option (option 3)
- Initial health profile
- Deterioration due to aging
- Allowance made for replacement and partial replacement (refurbishment).

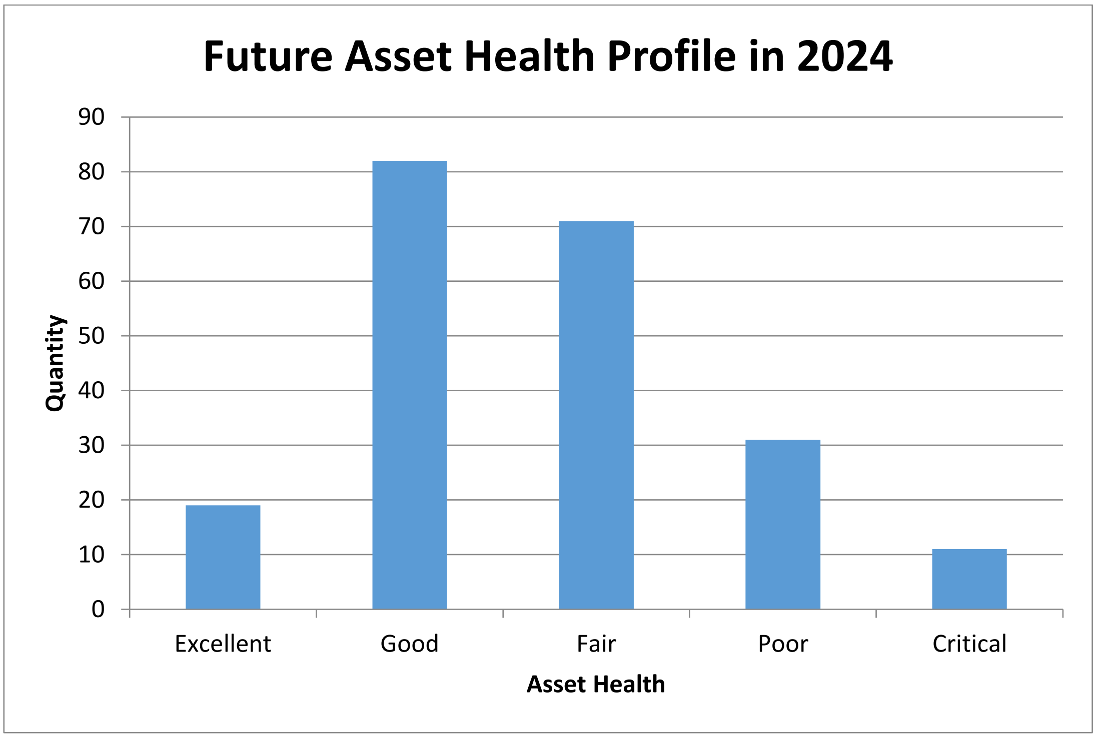

Figure 10: Asset Future Health Profile – UG HV Cables by Feeder Count

It is noted that the 2024 health profile depicts a population of assets that is in general, poorer condition as compared to the 2017 health profile. This is due to a considerably aged asset population, cost and resource constraints faced, as well as a higher risk tolerance for this particular asset class, as underground assets generally do not pose a safety risk.

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 asset replacement and network augmentation/expansion plans. See section 3.5 for planned network augmentation works.

Asset replacement activities involve minor replacement works in order to repair faulted assets (in which case a minimum of 10 metres of cable is replaced and two joints are added), partial feeder replacement or full feeder replacement. Termination replacement is initiated by failure or condition based replacement.

Under the current strategy, a full or partial feeder replacement is undertaken only when a feeder's (or section of a feeder's) performance is at such a level that it can no longer be reasonably relied upon to continuously carry load. Terminations are replaced either after failure or only if an obvious failure predictor such as audible tracking occurs. Joints are added or replaced only reactively.

The recommended strategy will alter this approach in the following key ways:

- An additional mode of replacement – 'economic feeder failure'. In addition to feeder replacement due to inability to remain in-service, a feeder may 'fail' and require replacement as a result of a series of tests organised in to a three-tiered system. This scenario translates in to a calculated 'condition' of zero for the feeder in question. Failing these tests can lead to full feeder replacement or single length replacements between switching points. Each case will be analysed individually based upon synergistic works and cost-benefit analysis.

- A list of all feeders with an UG cable component ranked by health score will be produced, which will allow for a structured replacement program if chosen to implement one.

- Cable terminations will be proactively replaced based on results from PD testing before they fail.

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 corrective maintenance appropriately adapted to ActewAGL operating environment and service conditions.

Underground assets inherently do not lend themselves to life-extending preventative or corrective maintenance works. Cables and terminations generally operate continuously until they fail, at which point they are replaced. That being said, by replacing potentially at-risk cable segments before they fail, the lifespan of the overall underground feeder asset can be extended by way of reduced fault current and fault-finding current occurrence within the network.

For this asset class, it has been determined that the most effective approach is to employ condition monitoring in order to identify assets to replace before failure. The below table summarises the proposed tasks for each asset type.

Asset Type	Maintenance / Monitoring Task	Trigger
HV Cables	Tier 1 - Desktop analysis	All cables
	Tier 2 - Tan-Delta, online Partial Discharge and Insulation Resistance tests	Worst performing feeders from Tier 1 per year
	Tier 3 - Off-line partial discharge test	Failing Tier 2
HV Cable Terminations	Partial Discharge test	To coincide with substation inspection program (5 yearly) and Hazemeyer RMU maintenance program (4, 6 or 8 yearly). Hazemeyer testing to initially be expedited in order to test entire population.

Table 16: Proposed Condition Monitoring Task Summary

6.2.1 Condition Monitoring

6.2.1.1 Cable Testing

Poor performing cables as defined within Tier 1 desktop-analysis will be subject to two tiers of physical cable testing. This has been split into two tiers in order to spare the underground network from undue disruption, as certain types of testing require feeders to be segmented into 2km segments (dictated by accuracy requirements of results) thus reducing overall condition. However, these types of tests tend to have a higher degree of accuracy with respect to defect location, and therefore make up the final tier of cable testing.

ActewAGL plans to assess the condition of eight feeders annually, comprising of tier 2 and tier 3 tests.

6.2.1.2 Termination Testing

The vast majority of cable terminations are situated within substations, which are subject to five yearly visual checks under the substation maintenance program (separate to this asset class).

It is proposed to incorporate handheld PD testing of these cable terminations as part of the standard inspection routine. This will detect loose connections, high resistance connections, and potentially hotspots (which generally have a PD signature, dependent on root-cause).

ActewAGL plans to test all 1,100 Hazemeyer unit terminations by 2019, and all 3,700 RMU terminations by 2024. To achieve this, a program is to be created in order to test high all Hazemeyer terminations in a shortened timeframe than that allowed by standard routine inspections. This program is to fall within the distribution substations portfolio.

6.3 Asset Disposal Plan

Cables which will be replaced or cease to be utilised in the future should be physically removed where economically viable. However, most unused cable have historically been abandoned and left underground due to costs associated with removal or access problems.

Recovered cables are scrapped to recover the copper screen wire, and copper and aluminium conductors from the cable. It is proposed for ActewAGL to perform residual life assessment on samples of high voltage underground cable when the opportunity presents to build up a database to help determine the rate of ageing for comparison with similar in-service cable with the same age, manufacturer, type, and installation condition.

Care must be taken to responsibly dispose paper insulated cables, as well as cast iron and porcelain cable terminations. Paper insulated cables are mass-impregnated with oil compounds and may contain bitumen on the surface of the metallic sheath. Cast iron and porcelain cable termination may have oil or compound filled inside the insulator.

The disposal procedure for underground cables is documented in the document "Recovery and disposal of reclaimed network assets" (IMS document PR5017).

6.4 Associated Asset Management Plans

Asset specific plan – Distribution Enclosures

- Relates to partial discharge testing during 5 year inspection program

6.5 Asset Strategy Optimisation Plan

Future developments enabled by the implementation of this asset management plan:

- Enhanced desktop analysis of feeder health resulting from known cable weak-spots and further correlation of this to environment, cable type, loading, etc.
- Enhanced record keeping and trending analysis using condition monitoring outcomes.
- Installation of fibre optics along high importance feeder sections (i.e. first run out of a zone substation) which can give real time indications of cable operating temperature and fault location capabilities. This is a technology option that AAD may research and pursue in the future.
- Utilisation of ADMS cable fault prediction capabilities.
- Introduction of additional FPIs within the HV network to aid with fault finding.

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 preventative maintenance, corrective maintenance and condition monitoring.

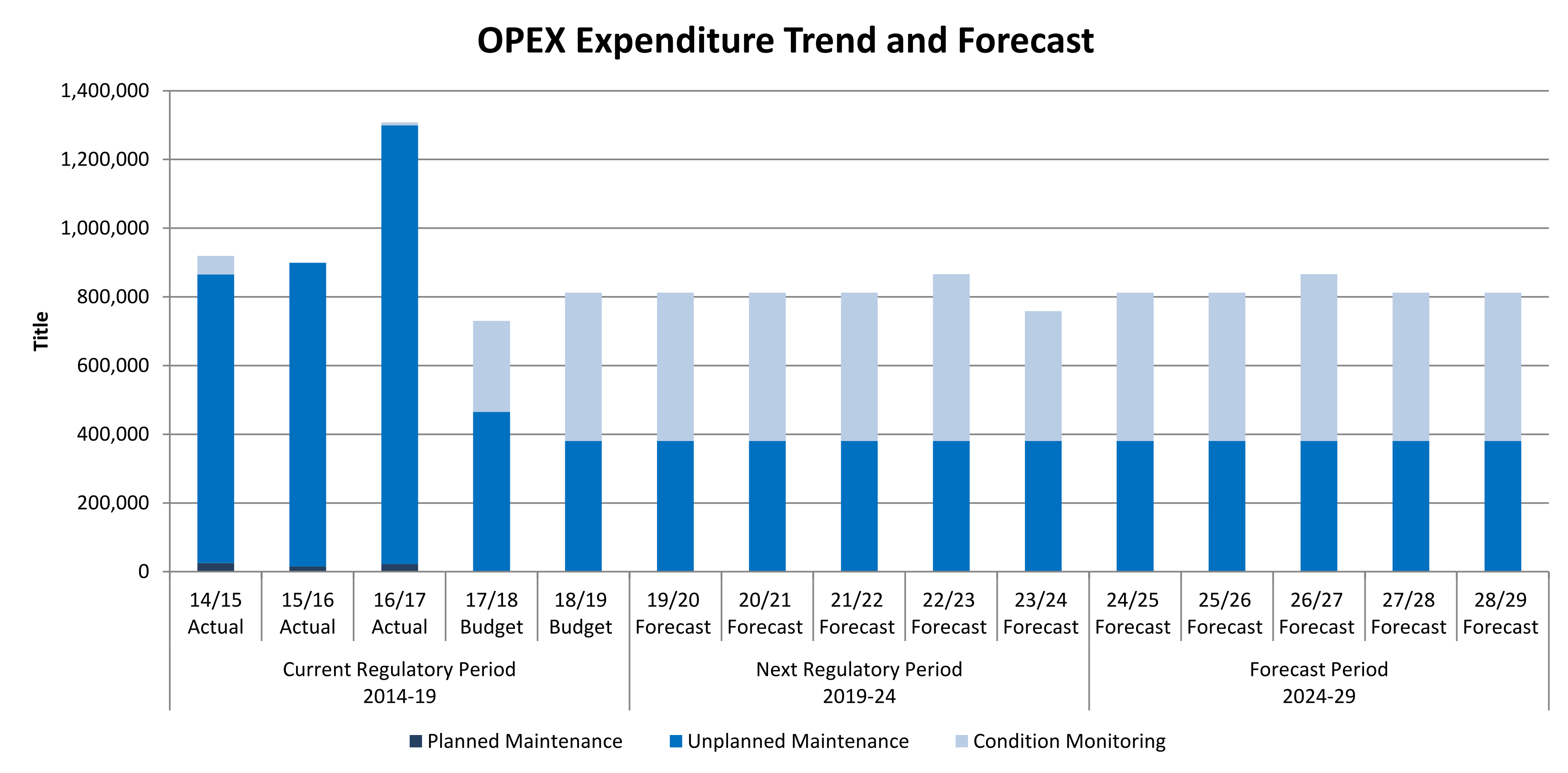

Figure 11: OPEX for Maintenance Program of UG HV Cable Assets

Program	Primary Assets HV Cable Maintenance and Condition Monitoring
2019-24 Budget	Annual OPEX budget for UG HV Cable Assets: **$812,311.**
Scope	This program includes: Failure investigation – root cause analysis Condition monitoring – cable tests Cable fault location activities – third party damage and genuine faults
Project(s) Details	**Maintenance and Condition Monitoring** The following maintenance activities are to be undertaken for UG HV cable assets on an annual basis : 8 – 11kV UG feeder cable tests 12- Cable fault root cause analysis 26 – Cable fault locations and associated repairs 3 – Accidental third party cable damage and associated repairs Note The above figures are average estimates of assets to be maintained, the exact quantity may vary over the five year period.
Risks and Opportunities	Cable condition monitoring allows for the identification and rectification of issues within the underground cable before failure occurs, and saves the business any potential loss of revenue and reputational risks due to failure and associated outage. Cable condition monitoring also provides an assessment of the condition of the UG cable assets, therefore optimising or justifying any potential ongoing replacement program.

Table 17: OPEX UG HV Cable Maintenance Program

7.2 Capital Program

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

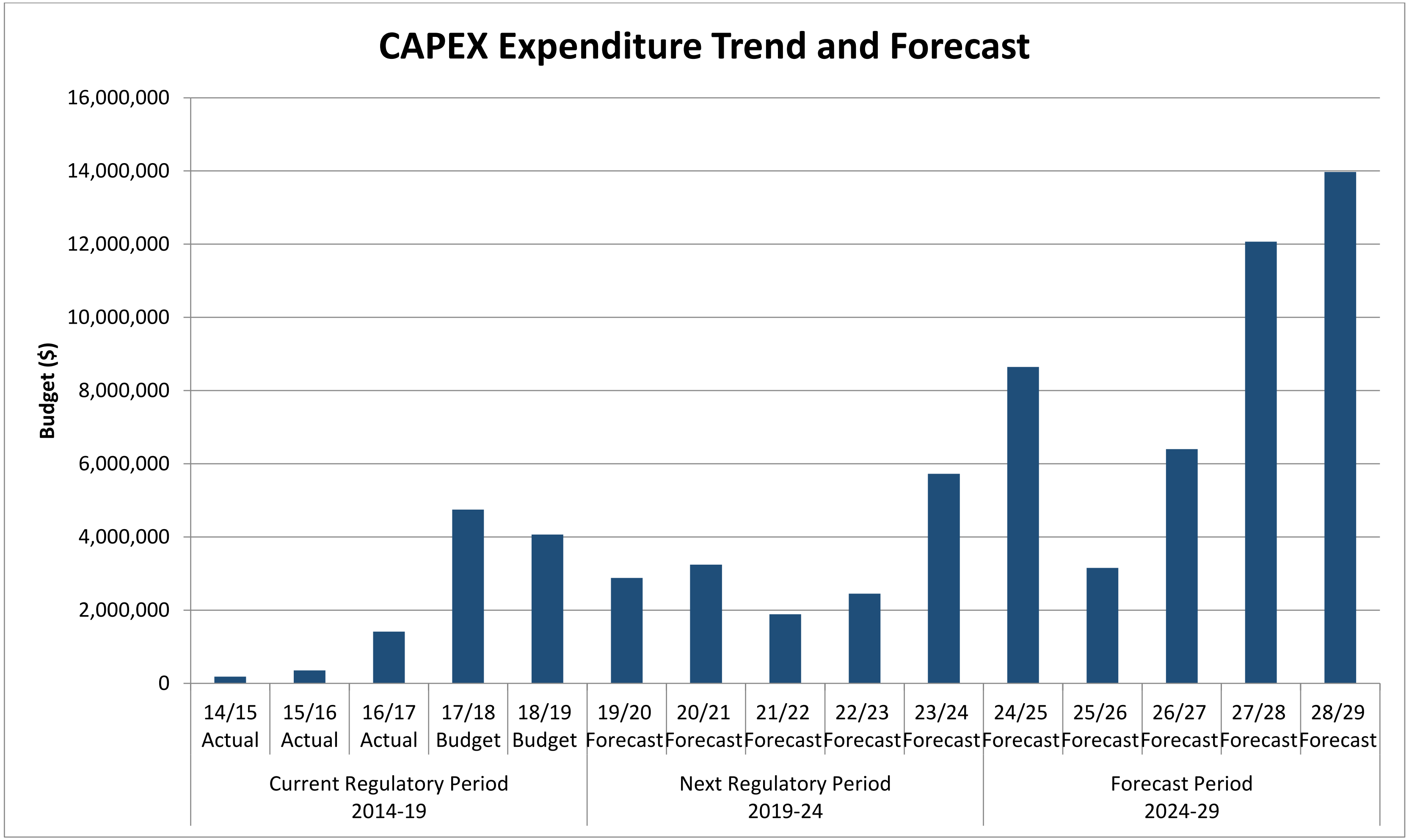

Figure 12: CAPEX Program for UG HV Cable Assets

S.NO	PROJECT TITLE	PROPOSED BUDGET ($)	NOMINATED YEAR
1	Sternberg feeder full replacement	2,285,767	2017/18
2	ANU Backup/Belmore feeder partial replacement	2,233,267	2017/18
3	Anthony Rolfe feeder partial Replacement	685,451	2018/19
4	Reid feeder partial replacement	442,752	2018/19
5	Meacham Bean feeder partial replacement	851,572	2018/19
6	Rowland-Pitman feeder partial replacement	607,917	2018/19
7	Shannon feeder partial replacement	330,301	2018/19
8	Langdon feeder partial replacement	404,988	2018/19
9	Nona feeder partial replacement	624,671	2019/20
10	Longmore feeder partial replacement	468,589	2019/20
11	Callister feeder partial replacement	541,602	2019/20
12	Baldwin Joy-Cummins feeder partial replacement	492,495	2019/20
13	Curtin North feeder partial replacement	270,610	2019/20
14	Cunningham feeder partial replacement	219,285	2019/20
15	Bissenberger Hawkesbury feeder partial replacement	612,448	2020/21
16	Lander feeder partial replacement	553,106	2020/21
17	William Slim feeder partial replacement	444,643	2020/21
18	Haydon feeder partial replacement	310,047	2020/21
19	Chuculba feeder partial replacement	405,290	2020/21
20	Folingsby feeder partial replacement	312,276	2020/21
21	Erindale feeder partial replacement	346,271	2020/21
22	Matthews feeder partial replacement	493,722	2021/22
23	Mundaring Russel feeder partial replacement	296,631	2021/22
24	Verbrugghen feeder partial replacement	203,026	2021/22
25	Wolseley feeder partial replacement	295,204	2021/22

S.NO	PROJECT TITLE	PROPOSED BUDGET ($)	NOMINATED YEAR
26	Deakin No. 2 feeder partial replacement	211,580	2021/22
27	Miller feeder partial replacement	126,772	2021/22
28	Symers feeder partial replacement	220,343	2022/23
29	Grimshaw feeder partial replacement	668,808	2022/23
30	Benjamin Laurie feeder partial replacement	435,689	2022/23
31	Miller feeder partial replacement	126,772	2022/23
32	Belconnen Way South feeder partial replacement	371,497	2022/23
33	Cowper feeder partial replacement	280,766	2022/23
34	Throsby feeder partial replacement	209,577	2022/23
35	ANU Backup – Belmore feeder full replacement	4,338,514	2023/24
36	Bowley feeder partial replacement	354,722	2023/24
37	Dairy South feeder partial replacement	289,314	2023/24

Table 18: CAPEX UG HV Cable Asset Replacement Program

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	**4,066,419**	**2,878,633**	**3,245,463**	**1,889,317**	**2,448,062**	**5,724,597**	**8,644,281**	**3,153,555**	**6,400,736**	**12,065,944**	**13,971,866**
OPEX	**812,311**	**812,311**	**812,311**	**812,311**	**866,311**	**758,311**	**812,311**	**812,311**	**866,311**	**812,311**	**812,311**
Planned Maintenance (OPEX)	0	0	0	0	0	0	0	0	0	0	0
Unplanned Maintenance (OPEX)	380,311	380,311	380,311	380,311	380,311	380,311	380,311	380,311	380,311	380,311	380,311
Condition Monitoring (OPEX)	432,000	432,000	432,000	432,000	486,000	378,000	432,000	432,000	486,000	432,000	432,000

Table 19: Total Budget Summary

The feeder replacement projects will be confirmed and justified with additional documentation and reports, as required on a case by case basis.

7.4 Program of Work Summary

The program of work for summary for 2018-24 is shown in Table 20.

Year	2018/19		2019/20		2020/21		2021/22		2022/23		2023/24	
Tasks	Units	Budget ($)	Units	Budget ($)	Units	Budget ($)	Units	Budget ($)	Units	Budget ($)	Units	Budget ($)
CAPEX	**33**	**4,066,419**	**32**	**2,878,633**	**33**	**3,245,463**	**32**	**1,889,317**	**32**	**2,448,062**	**30**	**5,724,597**
Replacement	**18**	**180,954**	**18**	**180,954**	**18**	**180,954**	**18**	**180,954**	**18**	**180,954**	**19**	**4,519,469**
Replace HV Cable Termination	18	180,954	18	180,954	18	180,954	18	180,954	18	180,954	18	180,954
Replace HV UG Feeder	0	0	0	0	0	0	0	0	0	0	1	4,338,515
Refurbishment	**7**	**3,805,041**	**6**	**2,617,255**	**7**	**2,984,085**	**6**	**1,627,939**	**6**	**2,186,684**	**3**	**1,124,704**
Refurbish HV UG Feeder	7	3,805,041	6	2,617,255	7	2,984,085	6	1,627,939	6	2,186,684	3	1,124,704
Reactive Replacement	**8**	**80,424**	**8**	**80,424**	**8**	**80,424**	**8**	**80,424**	**8**	**80,424**	**8**	**80,424**
Replace HV Cable Termination	8	80,424	8	80,424	8	80,424	8	80,424	8	80,424	8	80,424
OPEX	**75**	**812,311**	**75**	**812,311**	**75**	**812,311**	**75**	**812,311**	**76**	**866,311**	**74**	**758,311**
Unplanned Maintenance	**67**	**380,311**	**67**	**380,311**	**67**	**380,311**	**67**	**380,311**	**67**	**380,311**	**67**	**380,311**
Cable Fault Location	26	76,726	26	76,726	26	76,726	26	76,726	26	76,726	26	76,726
Investigate root cause failure	12	47,616	12	47,616	12	47,616	12	47,616	12	47,616	12	47,616
Repair cable due to third party damage	3	30,159	3	30,159	3	30,159	3	30,159	3	30,159	3	30,159
Replace HV cable section or joint due to in service failures	26	225,810	26	225,810	26	225,810	26	225,810	26	225,810	26	225,810
Condition Monitoring	**8**	**432,000**	**8**	**432,000**	**8**	**432,000**	**8**	**432,000**	**9**	**486,000**	**7**	**378,000**
Test HV UG Feeder	8	432,000	8	432,000	8	432,000	8	432,000	9	486,000	7	378,000
Grand Total	**108**	**4,878,730**	**107**	**3,690,944**	**108**	**4,057,774**	**107**	**2,701,628**	**108**	**3,314,373**	**104**	**6,482,908**

Table 20: Program of Work Summary

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.

A.1 Maintenance Task Costing

Unit costs for work on this asset class have been estimated by Program Development Branch. Details of the estimate are available in \\jeeves\energynetwk\Program of Work\future pow\AMP Reg Submission.

A.1.1 Planned Maintenance Tasks

Asset Type	Task	Unit Cost
HV Cables	Replace HV cable feeder section due to poor tested-condition.	$375 / m
HV Terminations	Replace HV Terminations that fail testing requirements.	$10,053

Table 21: Planned Maintenance Task Unit Costs

A.1.2 Condition Monitoring Tasks

Asset Type	Task	Unit Cost
HV Cables	Test HV Cables	$54,719
HV Terminations	Test HV Terminations	$-[3]

Table 22: Condition Monitoring Tasks Unit Costs

A.1.3 Reactive Maintenance Tasks

Asset Type	Task	Unit Cost
HV Cable	Investigate root cause failure	$3,968
HV Cable	Repair cable due to third party damage	$10,053
HV Cable	Replace HV cable section or joint due to in service failures	$8,685
HV Termination	Replace HV cable termination due to in service failures	$10,053

Table 23: Reactive Maintenance Tasks

[3] See ASP – Distribution Enclosures for estimates of this inspection.

Appendix B Risk Definitions

Appendix B provides reference information for 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

PROBABILITY of Failure	Failure Probability	Failure rate Lamda "λ"	Ranking
	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