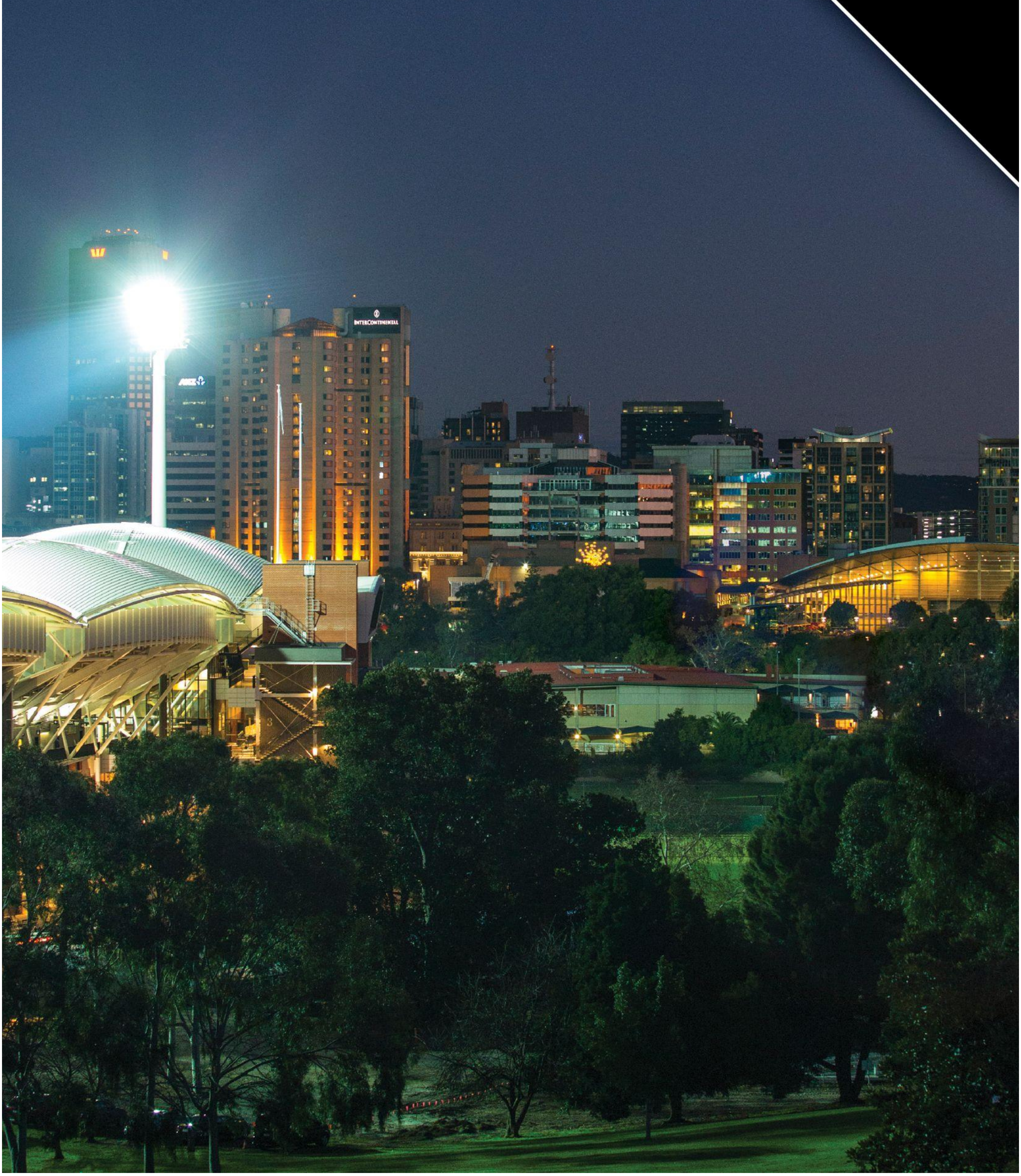
Attachment 9.1

SA Power Networks: Condition Monitoring and Life Assessment Plan (AMP 3.0.01)



ASSET MANAGEMENT PLAN 3.0.01
CONDITION MONITORING & LIFE ASSESSMENT METHODOLOGY

2014 TO 2025

Published: October 2014

SA Power Networks
www.sapowernetworks.com.au

OWNERSHIP OF STANDARD

Procedure 916 Annex B
Issue 2/13

OWNERSHIP OF STANDARD

Name of Standard / Manual: ***AMP 3.0.01 Condition Monitoring & Life Assessment Methodology***

Standard/Manual Owner - Title: ***Manager Network Asset Management***

Name: ***S Wachtel***

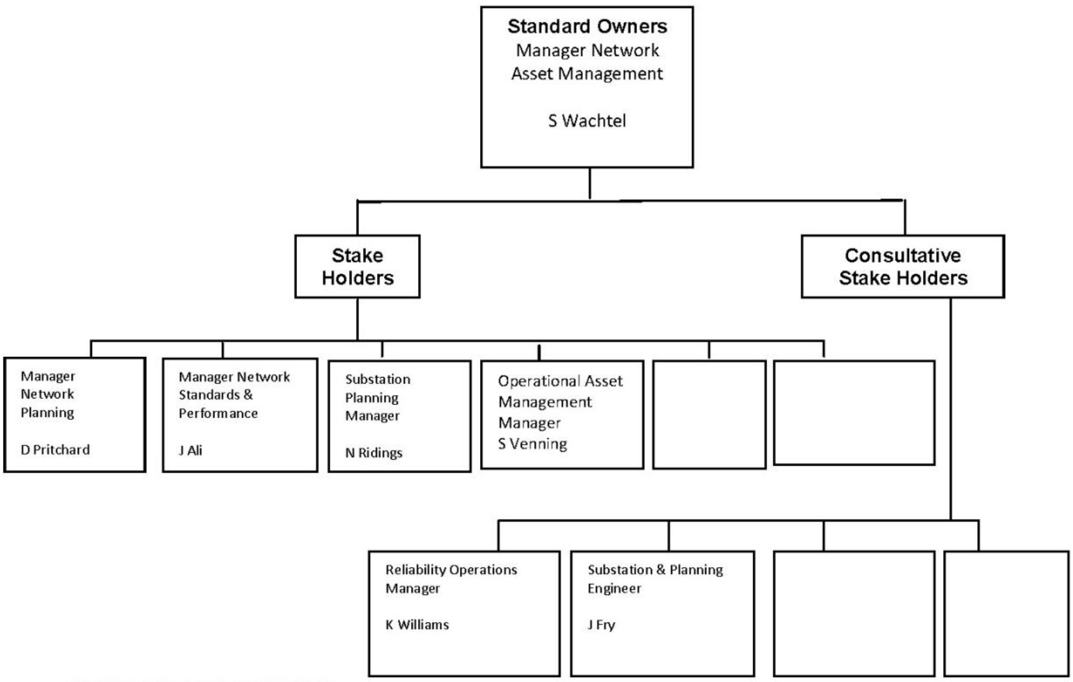
Standard Last Reviewed: September 2014

Standard Last Issued: October 2014

Review Period: 5 years

Next Review Due: October 2019 *(ie. When the next review process is due to commence)*

STANDARD/MANUAL OWNERSHIP STRUCTURE



OTHER RELATED MANUALS

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COMMENTS

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(Asset Management Plan 3.0.01 – CMLA)

DOCUMENT HISTORY

Date	Version	Explanation
6 /5/2009	1.0	Initial Release
8/8/2014	2.0	Final Draft incorporating reviewers comments
28/10/2014	4.0	Final

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1. EXECUTIVE SUMMARY

The Condition Monitoring and Life Assessment (CM&LA) methodology forms a key input into SA Power Networks' Asset Management Strategies and plans. This document defines and provides information on the CM&LA approach, as applied to the current Asset Management Plan and as used in the formation of the detailed Asset Management Plans for each asset class.

SA Power Networks' historical strategy of generally only replacing an asset after a catastrophic failure is no longer considered appropriate. Large proportions of SA Power Networks' major assets were installed in the 1950s to 1970s and are expected to create a bow wave of replacement requirements when they reach their end of life. That is, a significant increase in service failures of major assets is predicted, as many assets have moved beyond their industry standard lives.

SA Power Networks considers the consequence of a dramatic increase in service failures as an unacceptable safety, reliability, environmental and business risk. It is not consistent with our legislative obligation to operate and maintain a safe electrical network. For example, it is unacceptable to wait until a major substation transformer fails with an emergency period of seven days with thousands of customers without supply during this period. Similarly, it is unacceptable to increase the risk of bush fire starts due to in service failures of line hardware such as conductors or poles.

Continuing with SA Power Networks' historical asset management strategy will result in:

- Increased supply restoration activity
- Deterioration in reliability performance and possible non-compliance with reliability obligations
- Reduced supply security
- Increased liability claims for avoidable events
- Premium cost to replace.

SA Power Networks has chosen to replace on condition as the alternative strategy to its historical strategy as it:

- Provides least cost solution
- Selects the asset most likely to fail
- Optimises Capital Expenditure (CAPEX)
- Provides best supply security and reliability outcome
- Maximises asset life
- Consistent with good industry standard practices

In order to implement a replace on condition strategy, SA Power Networks will purchase and implement condition monitoring equipment, programs and tools. SA Power Networks has already implemented Condition Based Risk Management (CBRM) models for its priority assets, as well as a field data capture tool to collect condition information about them. In the future, SA Power Networks plans to implement CBRM models for the Protection and Control, Underground Cables, Ground Level Switchgear and Reclosers & Sectionalisers asset types. SA Power Networks also plans to undertake online and offline Partial Discharge (PD) testing, online dissolved gas analysis (DGA) monitoring, and trip profiling for its substation assets; increased underground cable testing; increased inspections for compliance with the Network Maintenance Manual; as well as research and development in fully utilising the Dynamic

Ratings Monitoring, Control and Communications (DRMCC) relays for condition monitoring purposes.

SA Power Networks' asset management strategy combined with its condition monitoring programs provides the most economically efficient solution to managing critical assets while meeting the regulated performance standards, and the right amount of CAPEX is invested at the right time.

2. INTRODUCTION

2.1 Purpose of Document

This document defines the CM&LA methodology used as a means to support SA Power Networks current Asset Management Strategy. The CM&LA approach is the key to the effective and ongoing management of SA Power Networks electricity distribution network assets. The document also summarises the key resource and technology gaps that need to be filled to successfully implement the asset management strategy over the period 2015-2020.

2.2 Background

SA Power Networks electricity distribution network is composed of a large number of assets which vary in:

- Physical size
- Cost
- Ages ranging from new to 70+ years
- Condition and remaining life
- Risk levels
- Failure Modes
- Impact on customers and businesses in the event of failure

Prior to 2007, SA Power Networks' approach was predominantly to have a 'fix on failure' strategy for the majority of asset types with a limited target replacement program for a small number of assets. This approach contributed to an increased CAPEX in 2006 and 2007 by a combination of the increased number of failures and increased costs per failure.

In June 2007, SA Power Networks initiated a change in condition monitoring and life assessment strategy. The drivers for this change in approach included the following:

- Increasing supply restoration activity
- Increasing asset failures leading to replacements
- Planned expenditure on replacement not sustainable without increased risk and reduced network performance
- Forecast age profile indicating large portions of network requiring replacement within next 20 years

In 2012, SA Power Networks engaged EA Technology to implement Condition Based Risk Management (CBRM) models for the following four classes of assets: Poles, Overhead Conductor, Substation Transformers and Substation Circuit Breakers. These assets represent approximately 80% of CAPEX, and are known as the Priority Assets. CBRM models identify the level of risk exposed by each asset, so that the optimum replacement year can be determined. In order to improve the results obtained from the CBRM models, a Priority Asset Tool (PAT) for field data capture was commissioned in 2013.

The CBRM models and philosophy combined with the Condition Monitoring and Life Assessment approach seeks to manage the projected 'bow-wave' of CAPEX required for network asset replacements and augmentations by managing the risk within SA Power Networks so that the overall level of risk can be maintained and reduced to an acceptable level in accordance with our approved Safety, Reliability, Maintenance and Technical Management Plan (SRMTMO). Management of network assets is in accordance with SA Power Networks approved SRMTMP, other manuals, 'Good Industry Practice' and targeted asset replacements are made based on condition and risk assessment rather than on age alone, therefore providing optimal value for CAPEX investment.

A key element of the current asset management strategy for SA Power Networks is to effectively manage the lifecycle of assets under its control to ensure long term sustainable performance and condition of assets. SA Power Networks assets include primary network plant such as substations and transformer stations, overhead conductors and support infrastructure, cables, switchgear, transformers, public lighting, metering and telecommunications equipment. The Asset Management Plan and the Network Maintenance Manual define the key whole-of-life processes used to manage these assets in accordance with the Electricity Act and Regulations, and the Essential Services Commission of South Australia (ESCoSA) approved SRMTMP.

2.3 Condition Monitoring – Definition

Condition monitoring provides information on the operational and long term condition of the asset to enable asset decisions to be made including operations, refurbishment and replacement decisions. Condition monitoring is used to enable decision making that establishes an optimal balance between customer service needs, licence conditions, the provision of a safe environment, optimal return to shareholders and long term sustainable performance, in accordance with current SA Power Networks Asset Management Policy[1]

SA Power Networks has adopted a continuous improvement approach in developing and refining its condition monitoring and life assessment and making consequent changes to strategy implementation, ie changes to Asset Management and Network Management Plans.

2.4 Condition Based Risk Management Overview

CBRM utilises information, knowledge, engineering experience and judgement for the identification and justification of targeted asset replacement.

[1] Refer Asset Management Policy version August 2008, in Corporate Policy Manual

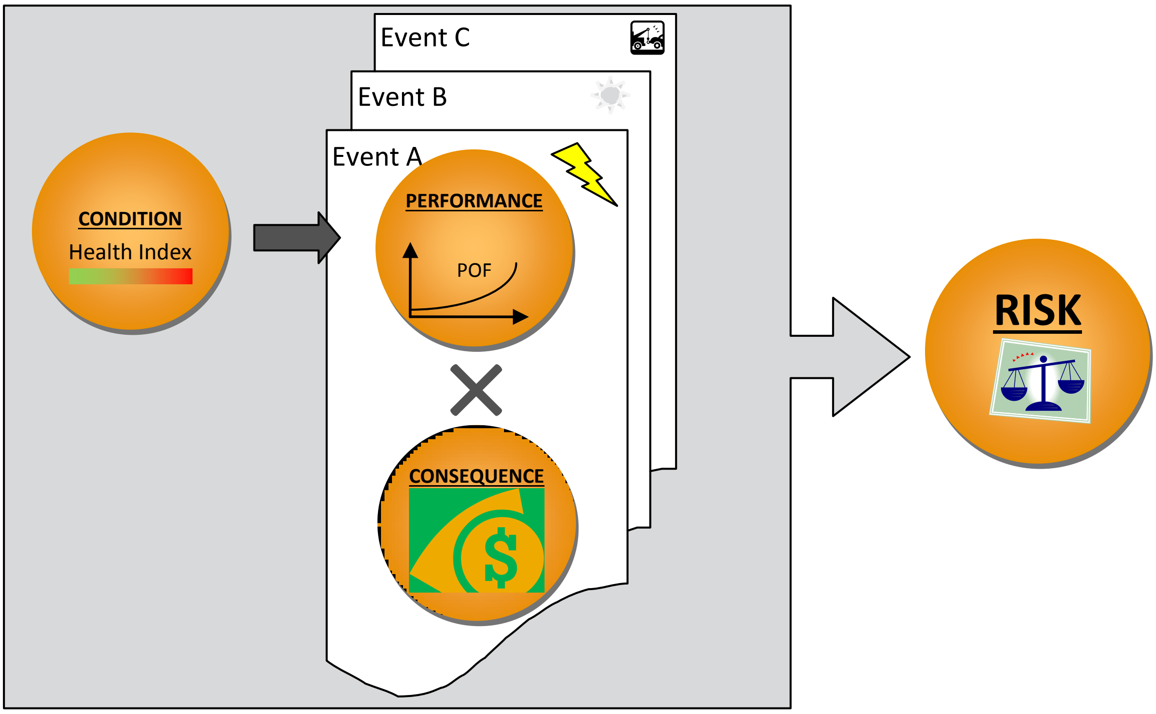

Figure 1: CBRM Process

CBRM determines the level of risk a particular asset exposes to SA Power Networks through the following steps:

1. **Define Asset Condition:** The condition of an asset is measured on a scale from 0.5 to 10, where 0.5 represents a brand new asset; this is defined as the Health Index (HI.) Typically an asset with a HI beyond 7 has serious deterioration and advanced degradation processes now at the point where they cause failure. Determination of the HI of a given asset is made by factoring its age, location, duty, and measured condition points. After the HI is determined, future condition of the asset is forecasted.
2. **Link Condition to Performance:** If an asset has a HI less than 5.5, its Probability of Failure (PoF) distribution is random. When the HI shows further degradation, a cubic relationship is used to measure PoF against HI. Each asset class has unique events; every event is assigned a PoF model, which uses an individual failure rate based on network observations.
3. **Determine the Consequence of Failure:** The consequence of failure is divided into the following categories:
   - CAPEX: The Capital Expenditure required to remediate an event
   - OPEX: The Operational Expenditure required to remediate an event
   - Safety: The cost incurred due to death/injury to individual(s) as a result of an event
   - Environment: The cost of environmental cleanup/penalties as a result of an event
   - Reliability: Financial penalties imposed if an event causes an outage

     The consequences are individually determined for all of the events associated with the asset using criteria such as location, number of customers, load profiles, SCONRRR category, and type/model.
4. **Determine Risk:** Risk is measured in financial units. Risk is determined by combining the PoF, consequence and criticality for every event. Criticality defines the significance of a fault/failure for an individual asset, and is determined for each of the categories listed in item 3.

CBRM also models non-condition events, which do not depend on a HI. These events are assigned to every asset and use a random failure based PoF model. An example of a non-condition event is third party damage from a car hitting a pole.

CBRM determines the financially optimum year to replace a given asset by finding the right balance between delaying network investment and bearing more risk, a graphical illustration of this is shown below in Figure 2.

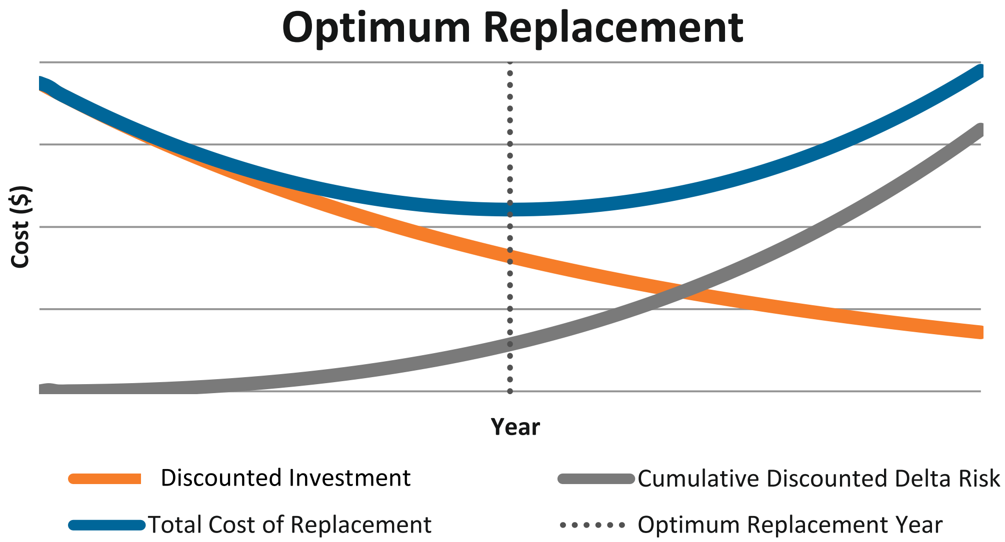

Figure 2: Determination of the Optimum Replacement

By forecasting every asset's condition, CBRM calculates the total risk, total number of failures and HI profile for an asset group based on the following investment scenarios:

1. **Do Nothing:** do not replace any assets in the group
2. **Targeted Replacement:** nominate when assets are replaced/refurbished
3. **Replace a fixed percentage of assets every year:** nominate the percentage of assets to be replaced every year and choose the priority to be HI, total risk or delta risk

CBRM identifies the level of risk exposed for an investment scenario over time. This allows the percentage used in **Scenario 3** to be determined such that a constant level of risk can be maintained, an example of this risk profile is shown below in Figure 3.

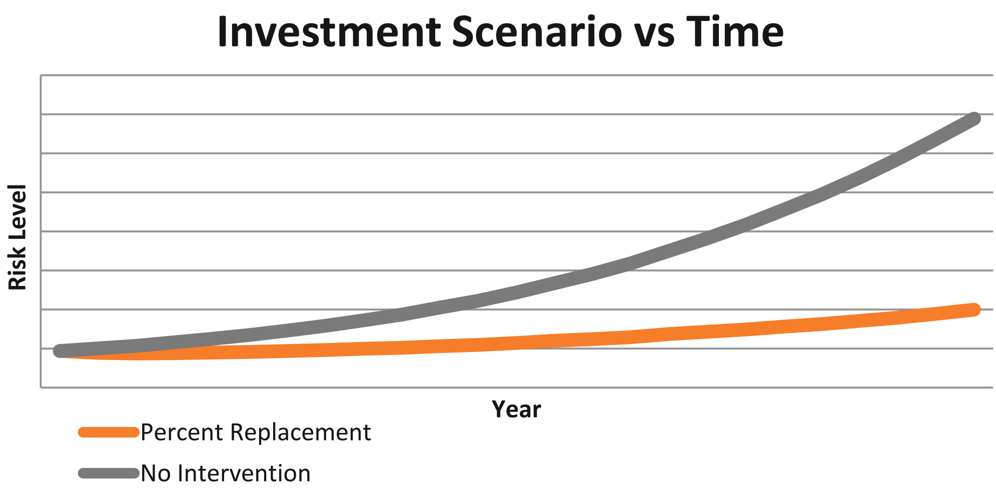

Figure 3: Level of risk exposed for an investment scenario over time

CBRM takes a net present value (NPV) approach for discounted investment, where the discount rate is SA Power Networks' Weighted Average Cost of Capital (WACC.) The cumulative discounted delta risk is a sum of the risk for each year, discounted by the WACC. The total cost of replacement is the sum of the cumulative discounted delta risk and discounted investment, CBRM finds the year where this cost is minimal and identifies this as the financially optimum replacement year for an asset.

3. ASSET MANAGEMENT STRATEGY AND PLANS

The current SA Power Networks asset management strategy is based on a CM&LA approach to the ongoing management of SA Power Networks electricity distribution network assets. The following subsections describe in more detail the process of asset management within SA Power Networks and the implications of changes made to asset management strategy.

3.1 Links between Policy, Strategy and Plans

SA Power Networks Asset Management Policy is determined and approved by the Board and states the following:

Purpose:

SA Power Networks is committed to managing its assets to provide valued services to our customers; comply with licence and regulatory obligations; provide a safe environment for employees, contractors and the community; and deliver optimal returns to shareholders.

Principles:

- *SA Power Networks will employ good asset management practice to deliver value from assets, to manage the life cycle of assets prudently and efficiently, and to ensure the long term sustainable performance and condition of the assets.*
- *SA Power Networks will prepare a Strategic Asset Management Plan which is reviewed on an annual basis.*
- *The Asset Management Strategies, Objectives and Plans will be founded on provision of the levels of service that our customers and the community seek and are prepared to pay for, delivered the most cost effective way, whilst also meeting Regulatory obligations and Corporate Strategic Objectives.*
- *SA Power Networks shall establish, implement and maintain processes and procedures for identifying opportunities and assessing, prioritising and implementing actions to achieve continual improvement in asset management.*

The current Asset Management Strategy links to this asset management policy in that it strives to optimise CAPEX investment though targeted replacement and refurbishment of assets, based on an assessment of asset condition and risk. This Asset Management Strategy also seeks to provide sustainable lifecycle management of assets through use of condition monitoring and life assessment techniques.

Detailed Asset Management Plans are based on the Asset Management Policy and Strategy, for each distribution network asset at the optimum class and sub-class level. The aim is to deliver optimal returns to shareholders and long term sustainable performance.

The Asset Management Plans detail the design and implementation of a maintenance and replacement strategy for each asset class or sub-class that enables delivery of known regulated performance standards and business accepted level of risk.

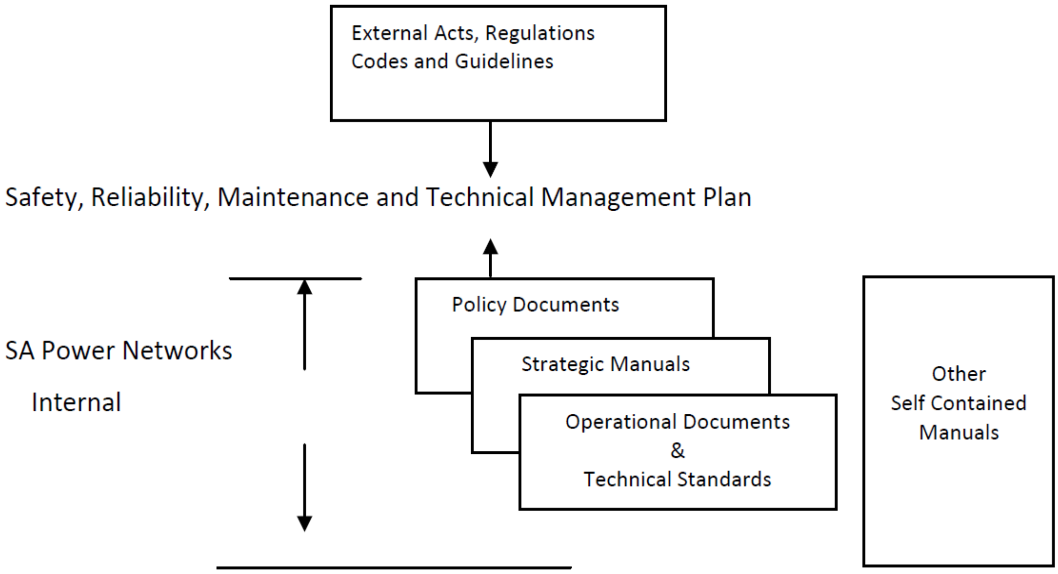

Figure 4: Key Asset Document Hierarchy

3.2 Condition Monitoring – Annual Review Process

SA Power Networks currently reviews its Asset Management Plan annually and Individual Asset Management Plans every 5 years, taking into account changes in areas such as:

- Customer expectations
- Regulated standards
- Industry standards
- Asset performance
- Demand impact
- Results of the present level of condition and performance monitoring
- Business objectives
- Business risk tolerance
- Improvements

The change in Asset Management Strategy in 2007 to implement a Condition Monitoring and Life Assessment Methodology has improved the level and quality of information and data available to inform this review process, and therefore enabled SA Power Networks to better target asset replacements to provide optimal value for CAPEX investment. Key projects implemented as part of the new Asset Management Strategy included CBRM modelling for the priority assets, and the PAT for improved field data capture. Further information about CBRM and PAT can be found above.

3.3 Drivers for Change

The drivers for a change in approach to Asset Management Strategy include:

- Increase in supply restoration activity
- Increase in network asset failures leading to replacements
- Increasing planned expenditure on replacement deemed to be not maintainable without accepting increased risk and reduced network performance
- Age profile indicating large portions of network needing replacement within the next 20 years

The increasing failure rate is illustrated in the following graph, Figure 5.

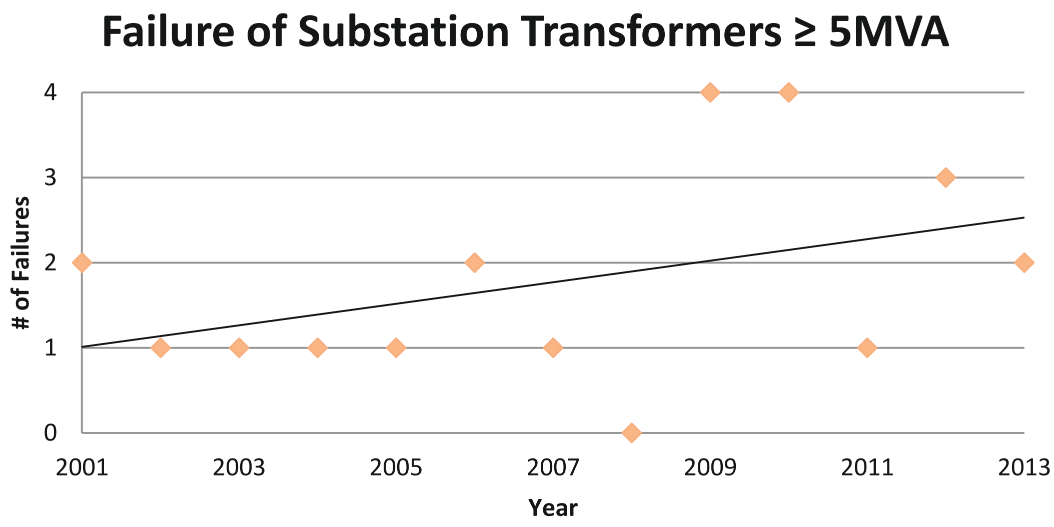

Figure 5: Substation Power Transformer Failures ≥ 5MVA

The impending problem of replacing a large number of aged assets over a short period of time is illustrated in the two examples (one substation and one line asset class) shown in Figure 6 and Figure 7.

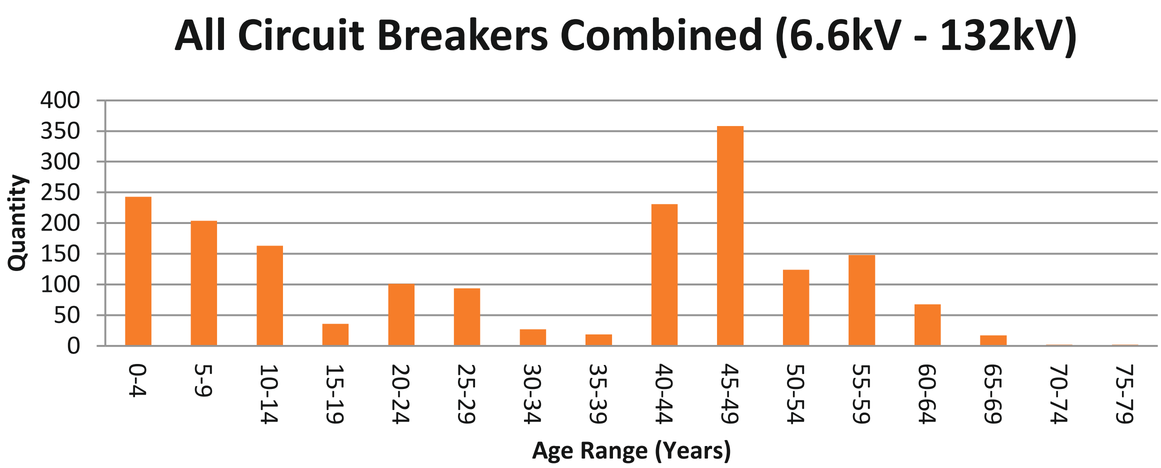

Figure 6: SA Power Networks All Circuit Breaker Age Profile

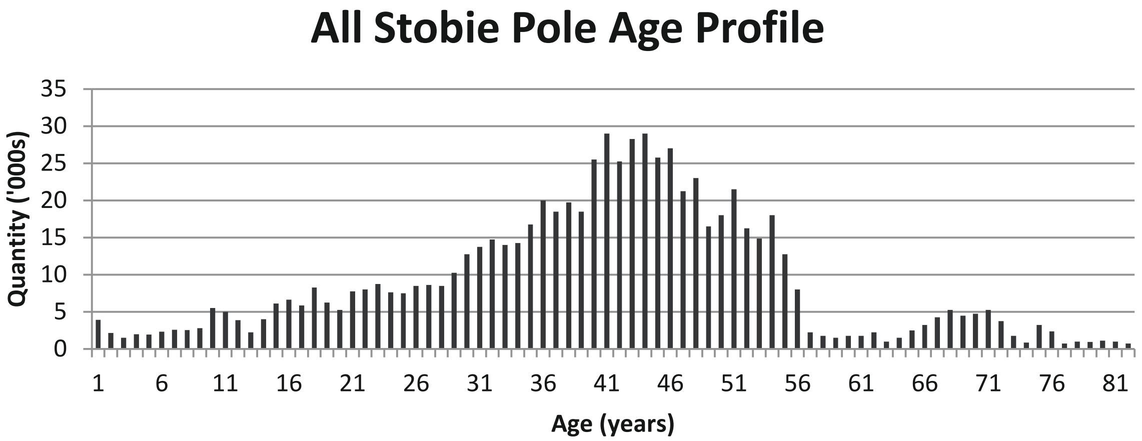

Figure 7: SA Power Networks Stobie Pole Age Profile

The current Asset Management Strategy is aimed at managing the projected large number of assets reaching the end of their reliable operational life within the regulatory period (often referred to as a 'bow-wave' of CAPEX.) This CAPEX is required for network asset replacements and augmentations to ensure that assets are managed within SA Power Networks current policy risk settings (ie 'low residual risk') in accordance with 'Good Industry Practice' as outlined in the SRMTMP and associated hierarchy of documents. With targeted asset replacements based on condition based risk assessment, thus providing optimal value for CAPEX investment.

3.4 Condition Monitoring and Life Assessment Continuum

SA Power Networks manage the network assets to provide a balanced outcome that meets shareholder, risk, license and customer objectives.

The average age of network assets has steadily increased along with the coincident risks associated with aging assets that is characteristic of many distribution companies in Australia and overseas. Increased Condition Monitoring and CBRM modelling on more asset classes will be used to provide better knowledge on the condition of the assets to enable better asset decisions to be made, such as replacement time and maintenance intervals and to manage risks associated with asset operations.

Accurate and timely information on condition is a critical element of the management of aging assets and the implications of increased asset age to allow investment decision optimisation and effective network risk management.

More predictive maintenance and asset replacement effectively means replacement at the optimal time, usually judged as the best balance between risk exposure and delayed investment costs as shown in Figure 2. Optimal maintenance decisions or condition based maintenance represents advancement from the past practice of predominantly time-based intervals to maintenance intervals based on actual asset condition as determined by a condition monitoring regime.

The introduction of newer and more automated technology for data collection, monitoring, analysis and testing will introduce efficiencies that lead to a gradual levelling or reduction in OPEX resources needed for Condition Monitoring. This will, however, be offset by an increase in CAPEX to implement these new technologies and systems. The extent to which such trends will eventuate within SA Power Networks depends, to a large degree, on:

- The cost effectiveness of the new technologies to SA Power Networks business needs and the subsequent uptake of such technologies

- The mix of assets that comprise SA Power Networks network and their age/condition profiles

SA Power Networks will continue to monitor trends and developments in CM&LA into the future and take a measured and prudent approach to improvements over time, with annual reviews built into the normal business planning process and feeding back into Asset Management Strategy and plans for implementation, with resultant changes to OPEX and CAPEX requirements.

3.5 Consequences of Maintaining Previous Strategy

The alternative to the current Asset Management Strategy was to continue with the previous largely 'fix on failure' strategy for assets.

It is anticipated that maintaining the previous approach would:

- Increase OPEX for supply restoration
- Increase CAPEX for fix on failures
- Result in longer duration outages for some assets that can no longer be repaired
- Result in longer restoration times with increasing number of failures within a short time frame (eg multiple pole failures exceeding available resources including both labour and material to replace in a timely fashion)
- Increase likelihood of high risks such as bushfire starts and catastrophic equipment failures
- Increase in unit costs for both asset replacement and supply restoration activities (OPEX) through inefficient and un-coordinated 'piecemeal' replacement
- Result in worse network reliability as 'in service' failures increase
- Accelerate long term network deterioration as additional stress is placed on certain network areas as a consequence of customer load being diverted around asset failures (ie leading to shorter asset life or reduced flexibility in the network to deal with future contingencies).

The previous 'fix on failure' strategy resulted in increased expenditure in this category, by a combination of the increased number of failures and increased costs per failure.

The 'fix on failure' strategy reduces the opportunity for expenditure and resource planning in the timing of the replacement and the associated cost (labour and material), as well as impacting other planned work when resources are diverted to deal with the failure. Within the industry it is generally accepted that unplanned replacement costs significantly more than planned replacement (up to nine times more cost.)

3.6 CAPEX Scenarios for Alternative Approaches to Asset Management Strategy

SA Power Networks has considered the following strategies for Asset Replacement:

1. Top Down Approach – The available asset data and reliable failure data from the last 10 years is used to identify underlying trends in asset performance.
2. Bottom Up Approach – CBRM modelling is used to determine the annual replacement rate required to provide risk levels consistent with the requirements of the SRMTMP.
3. Business as Usual Approach – Expenditure remains the same as the previous reset period.
4. RepEx Modelling – Assets are considered as populations rather than individuals. The replacement life is used as a probability distribution and is defined in such a way that it adequately reflects the aggregate replacement needs across the population.

SA Power Networks has modelled each scenario for the priority assets choosing the most prudent and efficient result for replacement CAPEX. It's important to note that the most prudent and efficient scenario varies between the priority asset classes. The approach used is detailed in individual Asset Management Plans.

4. ASSET ASSESSMENT

The role of the Asset Assessment team is to populate the corporate system with information on our assets that is accurate, complete and current. This includes information about the location of the asset and the condition of the asset. With this information, SA Power Networks are able to make prudent decisions regarding our Asset Management.

Inspection types include:

- **Thermographic Inspections** – uses a thermographic camera to detect with thermal imagery, those components that have deteriorated due to a combination of corrosion and high load current to the extent that failure is likely. These inspections are conducted on overhead lines and in substations.
- **Switchgear Inspections** – specialist switchgear inspections are conducted to assess the condition of accessible components of the switchgear to identify hazards and components that have deteriorated to the extent that failure of the switchgear is likely.
- **Ground Component Inspections (GCI)** – these visual inspections assess in detail the condition of the poles, footings and guywires, including an assessment of mechanical integrity and the level of corrosion of channels on the pole.
- **Overhead Component Inspections (OCI)** - these visual inspections (using binoculars) assess in detail the condition of all other components on the pole, including conductors (conductor, fittings, tie wires, joints, services) and overhead equipment (switchgear, transformers, regulators, bushings, fuses, public lighting lamps).
- **Aerial Inspections** – SA Power Networks has a contract for outsourced aerial inspection and patrol services using helicopters. These are primarily utilised for annual pre-bushfire patrols but are also utilised for patrols that Field Services request, typically for storm related events.
- **Substation Inspections** – substations are inspected using a combination of visual inspection and thermographic inspection. Inspections include a check of the overall condition of the electrical assets (eg transformers, circuit breakers etc), the condition of all structural elements, the integrity of insulators and bushings, switchgear gas pressures (if applicable), security of the site (fencing), oil levels in oil based equipment, earthing connections, counter readings (for circuit breakers, reclosers).
- **Helidrone Inspections (Unmanned Aeronautical Vehicles (UAV))** – SA Power Networks engages Aerial Photography Specialists to undertake remote controlled aerial surveillance and photography using state-of-the-art micro UAVs. These are used in areas that cannot usually be accessed by full size helicopters where a top of the pole inspection is required that cannot be assessed visually (eg suspension construction on 66kV lines).
- **Aerial Lidar Inspections** – SA Power Networks are currently trialling Lidar technology to assess the benefits of vegetation scoping, vegetation auditing and asset inspection.

The asset assessment cycles are documented in the Network Maintenance Manual (No 12) and in the Line Inspection Manual (No. 11) and the Substation Inspection Manual (No 19).

The frequency of inspection is dependant on the corrosion zone, the fire risk and the criticality of the asset.

Corrosion Zones

Corrosion is a major cause of asset failure in SA Power Networks. SA Power Networks distribution area is divided up into three corrosion zones. The more corrosive agents that come into contact with an asset the faster the asset will deteriorate. As a consequence assets in the worst corrosion zones (zones 2 and 3) are inspected more frequently than those in zone 1. Typically assets in zones 2 and 3 are inspected every 5 years compared to every 10 years for assets in corrosion zone 1.

Asset Criticality

The impact of the asset failure is also taken into account with critical assets inspected more frequently than those that disconnect fewer customers on asset(s) failure. Thermographic inspections on subtransmission lines are conducted on 66kV lines every two years and on 33kV lines every 3 years. Thermographic inspections of distribution lines are conducted in the metropolitan area every 2 years and in the country every 5 years.

Bushfire Risk

The bushfire risk is playing an increasing role in determining the frequency of asset inspections. Currently Subtransmission Lines and Distribution Lines that are owned and operated by SA Power Networks in either High Bushfire Risk Areas (HBFRAs) or Medium Bushfire Risk Areas (MBFRAs) are patrolled in the period immediately prior to the declared Fire Danger Season. The patrols are not a detailed inspection but designed to pick up obvious defects.

In 2013, SKM were engaged by SA Power Networks to develop a Bushfire Risk Reduction Strategy report, which recommends increasing the overhead asset inspection cycles to five years for NBFRA assets, three years for HBFRA and MBFRA overhead assets rather than the current 10/5 year cycles used in accordance with the Corrosion Zones. The report states that the new cycles will more closely align with current industry practice undertaken by interstate utilities, and the effectiveness of the change will reduce the number of fire starts over the five year period.

Outstanding Work

In the past sample inspections rather than comprehensive inspections were carried out however this meant that the individual condition of most assets was unknown. Over recent years comprehensive inspections have been introduced however there are a significant number of assets that have not been inspected in the required timeframe. An increased inspection program is being undertaken to catch up and this will carry over past 2015.

Asset Information Collection

To perform accurate decision making, critical information about the assets needs to be known so that it can be used in CBRM assessments. Information on age, location, type of equipment and condition needs to be known. To gain this information a program of collecting data has been introduced. A collection tool called Priority Asset Tool (PAT) is used by the inspectors to enter information while they conduct their inspection. This tool was commissioned in 2013, and was developed through collaboration between SA Power Networks and ESRI.

Funding Allocations

The current OPEX funding for inspections in 2013/14 is $11.48M. However to comply with the strategy in the Network Maintenance Manual, increase funding of $8.88M per annum is required to:

- Achieve the 3/5 year inspection cycles as recommended by Jacobs

- Enhance cable testing
- Inspect 'hidden failure' assets
- Undertaken additional thermographic inspections
- Gain information critical to making CBRM assessments from the priority asset
- Gain information critical to making CBRM assessments substation condition monitors

5. FUTURE DIRECTIONS

5.1 Introduction

Our regulatory obligations relating to the provision of standard control services and the maintenance of the safety of our distribution system derive from a number of sources including section 60 of the Electricity Act, the requirements of our Distribution Licence, the ESCoSA approved Safety, Reliability, Maintenance and Technical Management Plan (SRMTMP), the various requirements relating to the maintenance of network assets referred to in the Electricity (General) Regulations (in particular, Section 12 of Schedules 1-4) and the ESCoSA-set service standards for reliability, that is, in accordance with clauses 5.2.1 and 5.2.3 of the Rules, we must maintain and operate the network in accordance with relevant laws, the requirements of the Rules and good electricity industry practice.

We must also comply with the power system performance and quality of supply standards as set out in Schedule 5.1.

SA Power Networks is required under the conditions of its Distribution Licence and section 25 of the Electricity Act to comply with its ESCoSA approved SRMTMP.

The internal SA Power Networks documents which form part of the SRMTMP include applicable standards and requirements for the rectification of certain types of network asset defects within a specified period after the identification of that defect. The Network Maintenance Manual (No. 12), in particular, specifies the inspection cycles for all asset categories and the assignment of maintenance priorities for those asset categories (i.e. the specified timeframes to rectify identified asset defects). In other words the SRMTMP defines what amounts to a network asset defect and mandates the timing for the rectification of that defect.

Condition monitoring provides information on the operational and long term condition of the asset to enable asset decisions to be made including maintenance, refurbishment and replacement decisions. Condition monitoring is used to enable decision making that establishes an optimal balance between customer service needs, licence conditions, the provision of a safe environment, optimal return to shareholders and long term sustainable performance. In addition condition monitoring information provides a measure of the effectiveness of the Asset Management Plan in achieving its objectives to minimise whole of life cost and risk and in ensuring long term sustainable performance and condition. Information is used to improve knowledge of the asset to adapt and improve asset management strategies to changing business needs, changing environment and changing levels of risk.

Broadly, asset management decisions are aimed at maximising business outcomes (for customers and shareholders) for minimum asset life cycle costs while minimising or optimising risks in line with SA Power Networks risk profile.

5.2 Technology

The SA Power Networks network consists of a diverse range of assets of differing technology types and at varying levels of sophistication. Corporate information management systems provide a range of avenues for collection, storing and analysis of the various types of condition and performance information that arises from these asset types. Over the last 20 years there has been a growth in the development and availability of methodologies and products to improve information collection and management.

Broadly information collection systems comprise the following key types:

- Management and collection of discrete data
- Management and analysis of on-line data
- Knowledge based interpretation and assessment of condition monitoring information
- Operational (near real time) systems such as SCADA systems used for key asset types such as substation and key field device information

There are a range of other corporate systems used to provide information on the static information related to assets such as geographic and mapping information systems, drawings and configuration databases. Further details of the supporting systems are included in the Asset Management Plan.

The SCADA system provides near real time network asset operational status. The fundamental purpose of the SCADA system is to provide operational information and its application for condition monitoring is limited without enhancement. SA Power Networks is currently upgrading its SCADA system from Citect SCADA to Schneider ADMS. This project will be completed within two stages, stage one being the installation of a demonstration and test data concentration system, stage two being the implementation of the switching management and decision support tool for operation and control of the electricity distribution network. This upgrade will provide a platform for the development of future smart grid technology.

5.3 CBRM Models

It is envisaged that over the next 5 years four new CBRM models will be created for the following asset classes: Protection & Control, Ground Level Switchgear, Underground Cables, and Reclosers & Sectionalisers.

5.4 On-line Condition Monitoring

SA Power Networks has introduced on line condition monitoring on critical assets and intends to trial the installation of other condition monitoring devices.

5.4.1 Thermographic Surveys

SA Power Networks conducts thermographic inspections of its substations lines and selected feeders. These thermographic surveys have detected hot joints and overheated components before failures occur. However not all feeders have been surveyed and there have been joint failures on these lines that may have been prevented if a thermographic survey had been undertaken. It is proposed to maintain the thermographic inspection cycle at a minimum of five years in all bushfire risk areas and extend the program to include all sections of feeders including low voltage (LV).

5.4.2 On line DGA of Power Transformer.

Yearly dissolved gas analysis (DGA) of power transformers is performed by SA Power Networks. A sample of oil is taken and sent to a laboratory. In other Australian utilities when a poor sample is obtained the frequency of sampling is increased and in some cases an online monitor is installed. The advantage of the online monitor is that samples can be taken under all loading conditions and a much better picture of the condition of the transformer can be built up. SA Power Networks will purchase 3 online DGA units costing $100K each.

5.4.3 Partial Discharge Monitoring

5.4.3.1 Partial Discharges (PD) from Metal Clad Equipment

An initial survey of metro sites using an Ultratev handheld meter has been conducted. A further survey of 75 sites in metro, near metro, and targeted country sites is planned. Two extra ultratevs are to be purchased to facilitate this survey at a cost of $25K each. The survey will take two test gangs approximately 3 weeks to complete.

Following this survey a continuous PD monitor can be installed. SA Power Networks has one semi permanent device whose inputs are connected to the outside of the metal compartments. The condition monitor measures ultrasonic waves and temporary earth voltage (TEV) generated due to PD of the equipment inside. This instrument is capable of being interrogated remotely in the future. SA Power Networks will purchase an additional two units at a total cost of $200K each held to monitor poorly performing switchgear.

5.4.3.2 Corona from Outdoor Equipment

A Radio Frequency (RF) detector can be used to detect PD in air (Corona) from outdoor equipment. While there are many devices that can perform this function the most useful are those that are directional and can tell where on a piece of equipment the PD is coming from. SA Power Networks will purchase a RF PD detector at a cost of $35K.

5.4.4 CB trip and close DC Current Detector.

The health of a circuit breaker can be monitored by analysing the DC circuit on a trip or close of the circuit breaker. The shape and length of the DC waveform gives information on a breakers condition. This information is most useful when a breaker operates for the first time (online test) but the monitor can also be used when the breaker is isolated (off-line test). Dedicated monitors for each breaker can be installed however it is more economical in SA Power Networks case to use portable devices that can be used on many breakers. SA Power Networks will be purchasing 2 units at $65K each.

5.5 Off-line Condition Monitoring

5.5.1 Partial Discharge Testing

A PD test set for assessing the condition of indoor switchboards and HSS CBs. This test set is particularly useful during commissioning. $150K has been allocated for the purchase of a unit.

5.5.2 Circuit Breaker Contact Resistance Testing

SF6 circuit breaker contact resistance has been found to be highly dependent on the test equipment and test current used. SA Power Networks will purchase two portable dynamic contact resistance testers each costing $150K

5.5.3 Cable Condition Testing

SA Power Networks has purchased new test equipment for cables. Over the next few years there will be a trial program of cable testing to determine the optimal use of the test equipment in terms of commissioning, routine maintenance and fault finding.

SA Power Networks will continue to adopt technology enhancements in line with industry direction and system availability where these innovations are consistent with business objectives. A core component to this strategy is the provision of asset knowledge to support optimised asset management decisions and the establishment of dedicated functions within the organisation to facilitate knowledge management and asset condition analysis.

5.6 Data Collection, Storage and Management

The achievement of SA Power Networks asset management strategy is dependent on the assessment, identification and adoption of the most suitable methods to provide information that monitors and assesses the condition of the asset providing information to facilitate optimised asset decisions. The derived information must be integrated and compatible with existing corporate information systems. The data collection storage and management will require additional head office resources to manage the information.

SA Power Networks information management systems have been evolving to meet business needs and in line with the evolution of asset management strategy. In the past, information management was document-based; the current trend is an increase in the use of specialist databases and analysis systems integrated with information in SAP. Industry need and business drivers has resulted in the development of a range of devices and information decision tools to assist utilities in asset data collection and asset decision making. Asset decision making has evolved to a more probabilistic and broader business based approach.

Some of the new innovations that have become evident in the industry over the last 10 years or so include:

- Enhanced analysis methods and knowledge management systems
- Field based computing and field capture devices – includes data collection at work level as part of work processes
- Spatial information systems
- SCADA enhancements to enable condition information to be extracted
- On-line continuous monitoring systems for some asset types

In future data already collected or to be collected by condition monitors have to be readily accessible by asset managers to make better repair/replace decisions. Intelligent devices in the field collect data and then this information is extracted by either:

- Reporting remotely on exception. An example of this is the DRMCC transformer condition monitor that receives many inputs from the transformer and sends alarms via the SCADA system.
- Interrogation data locally. An example of this is the PD monitor currently installed on a switchboard.
- Interrogation of data remotely. An example of this is the interrogation of relays from head office. This can be performed ad hoc or periodically. Relays can store condition information.

- Put all data or a subset of the data on a central server. An example is the thermographic photos of plant with hot joints that can be accessed via SAP.

Without careful planning on how best to retrieve or store data a utility can either be swamped with data or be collecting condition information and not having it readily available when required. SA Power Networks has allocated $300k to implement appropriate data collection management and storage of its condition monitoring information. In particular it will be assessed how best to recover and use information on transformer insulation condition, circuit breaker contact wear, battery condition and PD in switchgear.

6. TRENDS IN CONDITION MONITORING

6.1 Key Industry Trends

It is expected that within the next 5 years the following trends will be seen in the area of condition monitoring and related technology:

- Smart sensors and embedded probes in equipment supplied from manufacturers
- Increasing sophistication in available software and systems to provide condition monitoring
- More awareness and recognition of the importance of condition monitoring and associated knowledge management in the industry
- Moves towards common interface standards for condition monitoring and other substation equipment
- Increasing need to establish interfaces to corporate systems from operational and monitoring field equipment
- Increasing reliance on condition monitoring systems to perform predictive analysis for asset replacement, optimising maintenance timing, minimise unexpected failures and management of asset performance
- Lower cost of condition monitoring equipment (particularly for on-line types)

6.2 SA Power Networks Approach to Industry Trends

SA Power Networks will continue to monitor key trends in the industry and will prudently adopt technologies and processes that are aligned with corporate drivers as defined in asset management and business plans.

7. GOOD INDUSTRY PRACTICE COMPARISON

7.1 Industry Practices

In recent years, Transmission and Distribution utilities in Australia and world-wide have adopted a more focused approach to condition monitoring of network assets. This has been driven by the need for optimisation of shareholder returns, meeting regulatory requirements and satisfying customer service expectations. The initiatives and improvements identified in this strategy and in the resultant Asset Management plans for individual asset classes represent a balance between business, risk and service performance objectives.

The evolution of asset management practices in the general industry can be represented as a continuum shown below in Figure 8. The point that represents current practices on this continuum for SA Power Networks varies according to the asset class and the age of the technology available. For some asset types, such as distribution transformers the optimal and feasible management strategy at this time may be ‘fix on failure’ whereas large substation transformers may be best served by a strategy of condition based maintenance and replacement.

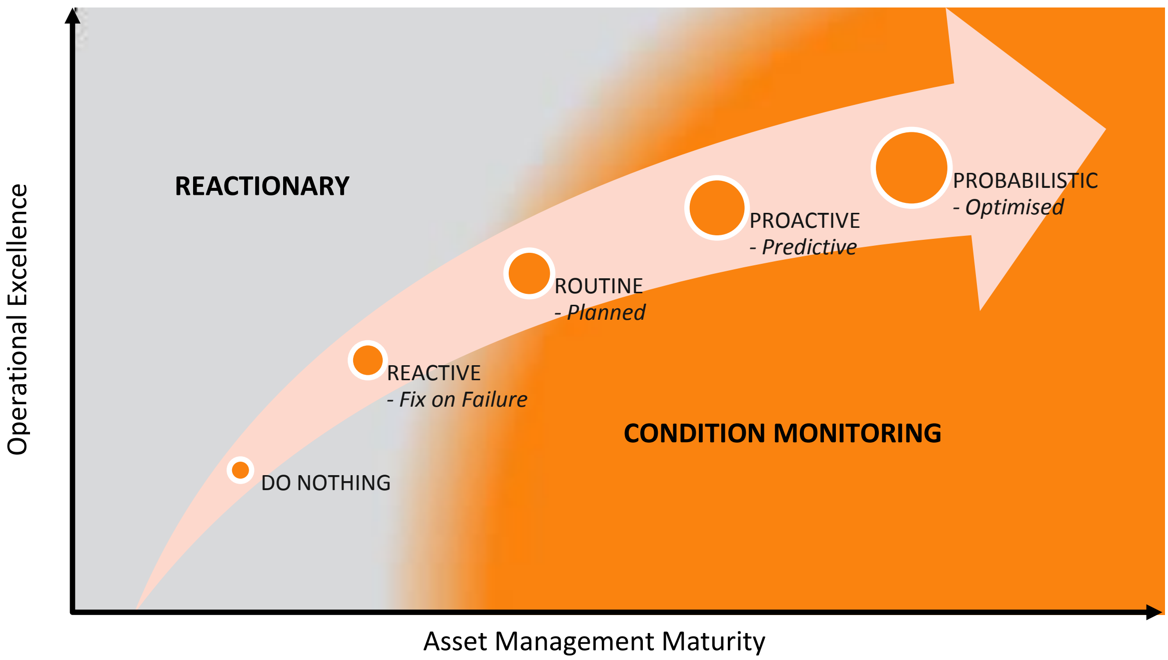

Figure 8: Electrical Industry Asset Management Continuum

The effective use of condition monitoring techniques is a key capability for SA Power Networks to be able to progress to further stages of the Asset Management continuum. Further implementation of condition monitoring will require the following key areas to be addressed:

- Staffing and training for field and office based personnel
- Information system augmentation and implementation
- Pilot and trial technology systems
- Capital investment in new technologies

7.2 Asset Management Evolution of Key Asset Classes

Table 1 broadly summarises the relevant asset management approach for key asset classes, and the future direction expected by industry trends and SA Power Networks' business needs.

Table 1: Asset Management approach for key asset types

Asset Type	Historical Approach	Enhancement	Future
Substations and transformer stations (general)	Routine inspection, routine maintenance, fix on failure	Improved information and condition assessment	Field knowledge management and data capture enabling predictive maintenance
Overhead conductors & support infrastructure	Inspections, fix on failure	Field computing devices, Aerial inspections	Predictive maintenance based on timely information and knowledge management

Asset Type	Historical Approach	Enhancement	Future
Underground cables	Fix on failure	Cable assessment and risk management	On-line and discrete monitoring and assessment. Predictive maintenance
Switchgear	Routine inspection, preventative maintenance	On condition maintenance based on improved knowledge	On-line monitoring (where justified). Predictive maintenance based on condition.
Power Transformers	Inspection, preventative maintenance, fix on failure, routine diagnostics (larger units)	On condition maintenance based on improved knowledge	Predictive maintenance based on condition. On-line condition devices (where economic), knowledge management
Instrument Transformers	Routine inspection	Routine testing and assessment	Predictive replacement, knowledge management on line systems (where justified by risk)
DC Systems	Routine maintenance and inspection	On condition maintenance based on improved knowledge	On line monitoring of asset condition. Predictive maintenance
Public Lighting	Fix on failure	Knowledge management	Optimised performance by improved knowledge management

SA Power Networks business needs will continue to evolve and will result in the adoption of new condition monitoring approaches as they become available and proven. A prudent and economic approach will be used to evaluate new technologies. SA Power Networks asset management practices will develop to encompass a more predictive approach to asset condition monitoring enabling maximum utilisation of the aging network asset base.

8. STRATEGY IMPLEMENTATION AND INVESTMENT IMPACT

SA Power Networks aim is to improve information on the condition and risk of its aging network asset to optimise asset management decision making. Investment in new technology associated with condition monitoring needs to be prudent and aligned with broader business objectives. In general terms investment is driven by a number of key factors:

- Safety - must not endanger the public, customers, employees, or other equipment
- Technical - must provide the functionality intended
- Customer – must take into account customer expectations
- Financial – must provide adequate return for shareholders
- Regulatory – must be aligned with licence and regulatory requirements

Enhancement of the CM&LA methodology includes the following activities:

- Increased and improved asset inspection, testing and diagnosis
- Adaption of maintenance practices to improve asset condition information capture
- Development and enhancement of information systems to support asset condition knowledge management
- Prudent investment in technology to provide discrete and continuous asset condition information
- Enhancement of operational SCADA system to maximise capture of condition information
- Enhancement of data analysis (existing data sources) to provide condition and life assessment knowledge
- Detailed Asset management Plans

8.1 Detailed Asset Management Plans

The current Detailed AMPs were developed incorporating the CM&LA methodology outlined in this document and in particular the process detailed in Appendix A.

8.2 CAPEX Plans

The direct CAPEX budget allocation for CM&LA in the next regulatory period is planned to develop four new CBRM models for the asset classes listed in Section 5.3. This additional CAPEX is detailed in Appendix B.

8.3 OPEX Plans

The change in Asset Management Strategy and consequent changes in asset management plans have resulted in corresponding impacts on projected OPEX.

Essentially the increase in OPEX required relates to the increased level of human resources needed to manage the consequent significant increase in the quantity and quality of data and information on network assets which will be required to effectively and efficiently manage the CM&LA function in SA Power Networks.

The following Table 2 summarises the identified key 'gaps' in resources to implement the new CM&LA plan.

Table 2: Key gaps identified in the CM & LA plan

Indentified 'Gap'	Solution	Key Assets Impacted
Asset Inspections: Requirement for compliance to Inspection Strategy in Network Maintenance Manual	Additional expenditure is required to complete inspection tasks outlined in the Network Maintenance Manual. Part of the step change is due to the focus of resources onto the OCI/GCI backlog. In addition, collection of condition information has started and the resource calculation is based on known resource requirements since the collection of this data began.	Overhead & Underground infra-structure
Substation Condition Monitoring: Requirement for operating new test equipment	Additional 1.5 FTE field personnel to undertake online and offline PD survey and monitoring, portable DGA monitoring, and Circuit Breaker trip profiling.	Substation Transformers & Circuit Breakers
Cable Testing: Requirement for undertaking diagnostics with the newly acquired cable test equipment	Additional 3 FTE field personnel to undertake cable testing and profiling.	Underground Cables

The additional OPEX required over the next reset period is detailed in Appendix C.

9. CONCLUSION

The enhancements in Asset Management Strategy have resulted in corresponding impacts on projected CAPEX and OPEX over the next regulatory period.

For CAPEX an additional amount of around $6.135M is anticipated being required for the development of four new CBRM models, additional systems for condition data storage and installation of condition monitoring equipment over the next regulatory period.

An additional $44.382M of OPEX will be required over the next regulatory period to ensure the Inspection Strategy complies with the Network Maintenance Manual, implement additional inspection programs, operate new substation test equipment, and operate new cable test equipment. The main areas of change in OPEX are additional human resources required due to significantly increased need and volume of asset inspection, and diagnostic tasks.

Refer to Appendices B and C for details of CAPEX and OPEX impacts.

A. APPENDIX A - Asset Management Strategy Process

A.1 Asset Lifecycle

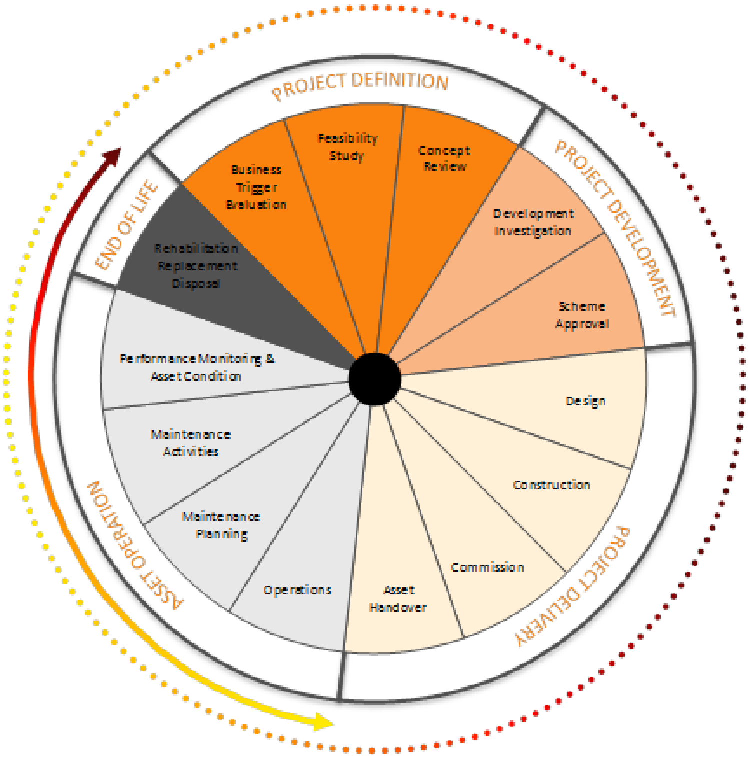

Figure 9: Asset Life-Cycle Wheel

There is a common profile to asset life-cycles. The life-cycle commences in its concept/design and culminates in its disposal or demolition. Each of the phases of asset life will attract a type of activity which is cognisant of the phase and which should be reflected in the budget.

The schedule of tasks undertaken during each phase will be dependent on the specific failure modes which are common to each. For example, asset replacement cycles will be driven by asset condition, size, maintainability, utilisation and functionality assessments.

From an asset management planning perspective, the asset management plans only deal with those aspects included in Figure 9 above as 'Asset Operation' and as 'End of Life' activities.

A.2 Asset Management Strategy – Maintenance & Replacement Process

Meets:

- Known Regulated standards
- Optimal return to shareholders
- Long term sustainable performance

Steps

1. Break network into asset classes based on functionality
2. Break asset classes into sub-classes based on
    - Age
    - Design
    - Geography
    - Consequences
    - Risks

3. Select dominant failure mode for each asset sub-class and identify any minor failure modes that need to be managed
4. Determine where in its asset life cycle particular sub-class is at (ie where will it be in 5, 10, 20 years) based on:
    - Number and nature of failures
    - Failure rate and recent performance
    - Industry practices and trends
    - Relationship to asset life knee-point
    - Is it past its design life?
5. Test the automatically selected strategy and eliminate the alternatives to determine:
    - Technical feasibility eg interval of useful condition monitoring, impact of condition monitoring on asset life
    - Economic viability, cost of condition monitoring vs benefits (including setup costs of monitoring), life extension vs replacement, NPV of strategy over 30 years, costs of spares strategy, cost of maintenance to meet design life, expected life remaining considering forecast duty
    - Ability to maintain or fix (availability of spares and skills)
    - Hazardous materials management
    - Risk before and after strategy (consequences of failure, availability of contingency plans and their time to implement, reliability, safety, unit cost, business and resource impact)

    If selected strategy fails the test, need to return to step 2 and re-run process (possible problems include too broad a sub-class, wrong failure mode, etc)
6. Quantify strategy in terms of operating and capital tasks and rates and spares and resources

A.3 Summary Legend

Asset Management Strategy

- Strategy 1: Monitor condition (inspection or test) and maintain/replace

  (1a) 10% of asset past knee point
  (1b) 10% of asset approaching knee point
  (1c) 10% of asset remote from knee point
- Strategy 2: Monitor performance (intrusive inspection, inspection, failure trends) and maintain/replace.

  (2a) Replace when fails test + accelerated age replacement
  (2b) Replace when fails test
- Strategy 3: Replace on failure. Asset sub-class near point of total replacement:

  (3a) Fix on failure + replace % to provide spares
  (3b) Fix on failure

Typical Failure Modes

(a) Signals impending failure (sudden reduction in performance due to corrosion, electrical stress, PD, insulation degradation)
(b) Wear and tear (gradual reduction in performance due to wear and age)
(c) Random
(d) Hidden

Table 3: Asset Management Strategies

Number	Strategy
1a	Condition Monitoring, maintain/replace on condition, with an accelerated total replacement plan
1b	Condition Monitoring, maintain/replace on condition, with increased spares holdings
1c	Condition Monitoring, maintain/replace on condition
2a	Monitor performance, maintain/replace based on test or performance with an accelerated total replacement plan
2b	Monitor performance, maintain/replace based on test or performance
3a	Fix on failure with a total replacement plan
3b	Fix on failure

Table 4: Automatic Strategy Selection for Asset Sub-Class

Failure Mode Number	Failure Mode	Strategy
A	Signal impending failure	1
B	Wear and tear	2
C	Random	3
D	Hidden	3

B. APPENDIX B – CAPEX Required for Condition Monitoring and Life Assessment Function

Additional CAPEX forecast due to CM&LA implementation is anticipated as follows:

- Ultrasonic testing units for poles and other line components to provide improved indication of pole condition
- Underground cable testing to provide predictive indications of imminent cable failure and for risk assessment of cable condition for targeted replacement programs
- Earth System testing equipment to improve knowledge of earth system condition to ensure safety for staff and public
- Stabilised binoculars to provide improved information for asset inspectors
- High powered cameras to assist in recording conductor and pole condition for later comparison and trending
- IT systems to store condition monitoring information, and
- CBRM models for additional asset classes as detailed below.

Table 5: Forecasted CM & LA CAPEX Variation

($'000)	Year 1	Year 2	Year 3	Year 4	Year 5	Total
CBRM models		$400		$400		$800
IT Systems to extract and store condition information		$150	$150			$300
Lines Test equipment	$931	$631	$781	$781	$781	$3,905
Total	$931	$1,181	$931	$1,181	$781	$5,005

Included in the above forecast are four new CBRM models for the following asset classes: Ground Level Switchgear, Underground Cables, Protection & Control, and Reclosers & Sectionalisers. These models are to be completed over the next five years.

The IT systems are required to extract and store information from existing condition monitoring equipment to make it available for asset management decisions.

Table 6: Additional CAPEX for the purchase of substation CM & LA equipment

($'000)	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Radio Frequency PD Detector		$35				$35
Dynamic Contact Resistance Tester		$150	$150			$300
CB DC current trip profiler				130		$130
Offline PD tester	$115					$115
Online PD tester					$200	$200
Handheld PD tester		50				$50
Online DGA Tester	$100		$100	$100		$300
Total	$215	$235	$250	$230	$200	$1,130

C. APPENDIX C – OPEX required for Condition Monitoring and Life Assessment Function

Table 7: Additional OPEX to operate the substation test equipment listed in Appendix B

($'000)	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Radio Frequency PD Detector	$13	$40	$67	$67	$67	$254
Dynamic Contact Resistance Tester	$5	$15	$25	$25	$25	$95
CB DC current trip profiler	$9	$28	$46	$46	$46	$175
Offline PD tester	$7	$20	$33	$33	$33	$126
Online PD tester	$6	$17	$29	$29	$29	$110
Handheld PD tester	$6	$17	$29	$29	$29	$110
Online DGA Tester	$5	$15	$25	$25	$25	$95
Total	$51	$152	$254	$254	$254	$965

Table 8: Additional OPEX to increase inspections for compliance with Inspection Strategy in Network Maintenance Manual

($'000)	Year 1	Year 2	Year 3	Year 4	Year 5	Total
No Access Poles	$4,896	$4,896	$4,896	$4,896	$4,896	$22,583
BRFA Frequency	$2,238	$2,509	$2,577	$2,609	$2,574	$12,507
Thermographic	$520	$520	$520	$520	$520	$2,600
Two person patrols	$550	$550	$550	$550	$550	$2,750
Total	$8,204	$8,475	$8,543	$8,575	$8,575	$40,440

Table 9: Additional OPEX to undertake underground cable testing using the newly acquired test vans and equipment

($'000)	Year 1	Year 2	Year 3	Year 4	Year 5	Total
Cable Testing	$596	$596	$596	$596	$596	$2,980
Total	$596	$596	$596	$596	$596	$2,980