# 2018-22
# POWERLINK QUEENSLAND REVENUE PROPOSAL

Supporting Document - PUBLIC

## Powerlink Queensland
## HV Underground Cable Asset Methodology



Delivering better value

# Powerlink – HV Underground Cable Asset Methodology - Framework

| | | |
|---|---|---|
| **Policy stream** | Asset Management | |
| **Endorsed by** | Manager HV Asset Strategies | [redacted] |
| **Authored by** | Group Manager Strategy and Planning | [redacted] |
| **Approved by** | Executive Manager | [redacted] |

## Version history

| Version | Date | Section(s) | Summary of amendment |
|---|---|---|---|
| 1.0 | 5/03/2009 | All | Migrated to new AM template |
| 2.0 | 21/12/2010 | All | Reviewed by [redacted] |
| 2.1 | 17/10/2014 | All | Reviewed by [redacted] |
| 3.0 | 12/11/2015 | All | Document review and to align with DMF |
| | | | |
| | | | |
| | | | |
| | | | |

## Table of contents

# 1. INTRODUCTION

## 1.1 Purpose

In order to implement the organisation's Asset Management Strategy a specific asset management methodology must be developed for each major asset group within Powerlink.

This document sets out the whole of life management philosophy for Powerlink's underground cable assets, provides a planning tool for asset management activities and acts as a reference for the development of maintenance and project plans.

## 1.2 Scope

This document covers the asset life cycle of the following Powerlink HV underground cable assets:

- underground cables forming a part of a transmission feeder
- underground cables located within Powerlink substations.

It excludes land maintenance activities and associated processes for vegetation management on underground cable easements, provision of access to the cables and management of corridors for co-use activities.




## 1.3 Objectives

Powerlink's asset management strategy ensures the organisation's assets are managed in a manner consistent with its overall corporate vision objectives to responsibly deliver electricity transmission services that are valued by shareholders, consumers, customers and the market in a safe, commercial and performance focused way.

The Underground Cable Asset Methodology considers the following matters:

- Identifies the statutory, economic and community obligations that drive the underground cable asset management methodology.
- Details the major tasks undertaken throughout the life cycle of the underground cables.
- Identifies some of the specific risks associated with underground cables.
- States the principal maintenance strategies employed by Powerlink in the management and application of underground cables.
- Identifies mechanisms to monitor performance and achieve continuous improvement in the management of underground cables over time.

## 1.4 Asset Management Overview

The key elements of the Powerlink's asset management framework can be summarised as follows:

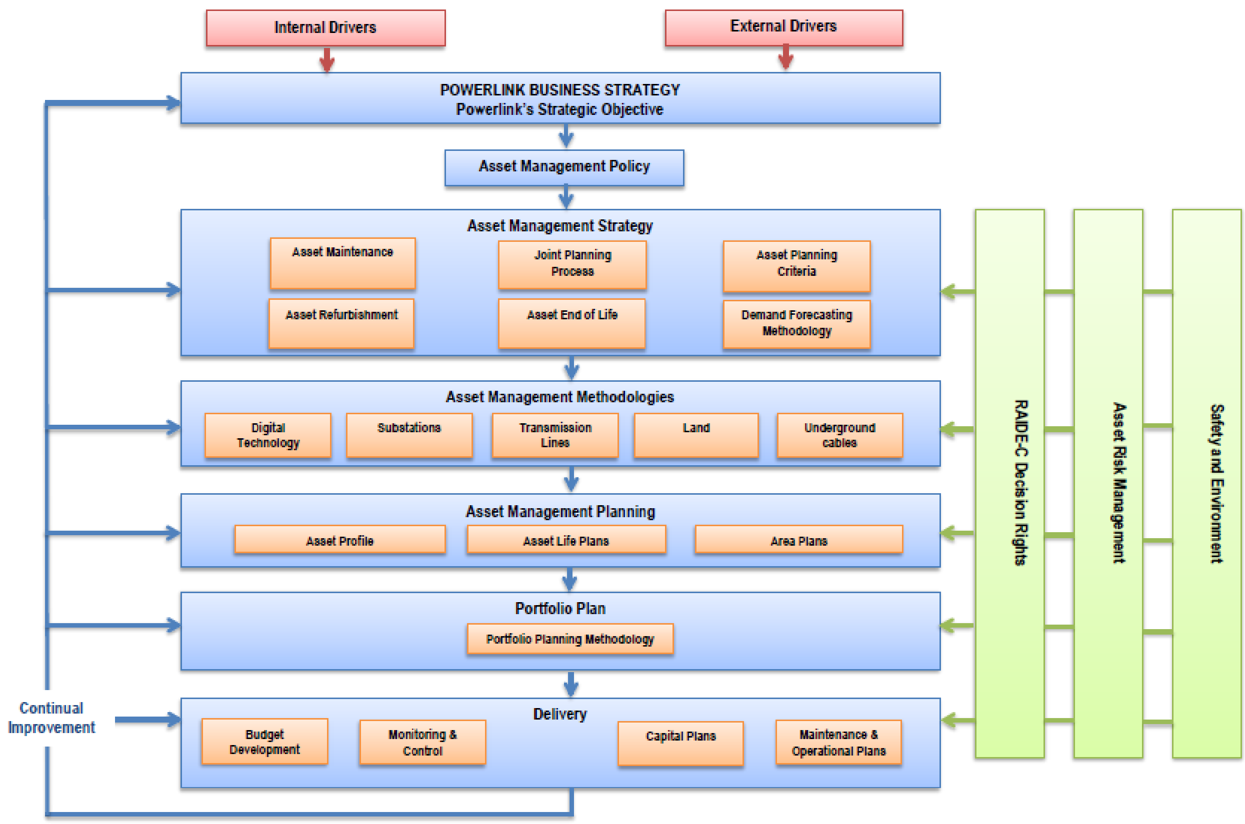


**Figure 1 – Asset Management Framework**

## 1.5 References

| Document code | Document title |
| --- | --- |
| ASM-I&P-STR-A969433 | Asset Management Strategy |
| ASM-I&P-FRA-A968358 | Powerlink – Land Asset Methodology – Framework |
| https://www.legislation.qld.gov.au/legisltn/current/e/electricalsa02.pdf | Electrical Safety Act 2002 |
| Electrical Safety Code | Electrical Safety Code of Practice for Works 2010 |
| https://www.legislation.qld.gov.au/legisltn/current/w/workhsr11.pdf | Work Health and Safety Regulation 2011 & relevant Codes Of Practice |
| https://www.legislation.qld.gov.au/legisltn/current/w/workhsa11.pdf | Work Health and Safety Act 2011 |
| Electricity Act | Electricity Act 1994 |
| NER | National Electricity Rules |
| EPA | Environmental Protection Act |
| AM-PR-0835 | Galvanised Bolts – Visual Grading Guide |
| WHS-P&C–STD-A1955230 | Electrical Safety Management System – Standard |
| ICNIRP guidelines | Guidelines for Limiting Exposure to Time-Varying Electric and Magnetic Fields (1Hz – 100kHz) Health Physics 99(6):818-836; 2010 |
| AM-POL-919 | Maintenance of Underground Cables and Extruded Insulation |
| AM-POL-920 | Maintenance of Self Contained Fluid Filled High Voltage Underground Cables |
| AM-PR-1093 | Overhead Underground Transition Site Maintenance |

## 1.6 Defined terms

| Terms | Definition |
| --- | --- |
| DBYD | Dial Before You Dig is a referral service for information on locating underground utilities anywhere in Australia. Powerlink provides our asset information to DBYD. |
| SCFF | Self-Contained Fluid Filled cables contain cable conductor, insulated with paper impregnated with a low viscosity fluid, which permeates the entire cable through the oil channel, ensuring that any voids are completely filled with the fluid. |
| "Turn Key" | Is the provision of a complete cable system including; design, procurement, construction, testing, spares. |
| EMF | Electric and Magnetic field produced from voltages and alternating current. |

## 1.7 Roles and responsibilities

| Who | What |
|---|---|
| Group Manager Strategies and Planning, I&P | Endorse the framework and support an undertaking to manage assets in accordance with this framework. |
| Manager HV Asset Strategies, I&P | Endorse action to manage assets in accordance with this framework. |
| Senior Line Strategies Engineer, I&P | Take action to manage assets in accordance with this framework. |
| Group Manager Technical and Network Services, O&FS | Ensure operational policies and procedures are in place in-line with this framework and perform audits on maintenance processes. |
| Group Manager Field Services, O&FS | Implementing Underground Cable Asset Methodology as part of field services. |
| Group Manager Specialist Services, O&FS | Auditing underground cable assets in the maintenance phase, including Ergon Energy. |
| Group Manager Network Operation Services, O&FS | Provision of fault data and analysis relating to underground cable assets. |
| Group Manager Infrastructure Delivery, ID&TS | Implementing Underground Cable Asset Methodology as part of Infrastructure Delivery. |
| Group Manager Infrastructure Technical Services, ID&TS | Aligning design and other technical services with Underground Cable Asset Methodology. |
| Group Manager Infrastructure Management Systems, ID&TS | Auditing the construction phase in-line with Underground Cable Asset Methodology. |

## 2. ASSET INFORMATION

Powerlink owns and operates a broad variety of high voltage underground cables at voltages from 11kV to 275kV. The age of underground cable assets is available from Powerlink's Annual Report.

Powerlink's Underground cables are typically feeder cables linking substations or overhead transmission line built sections where there are strict limitations on the available easements and/or electrical clearances.

The number of 11kV, 22kV and 33kV cables located in substations is not reported in the Annual Report separately, but is included in the substation statistics. To ensure their visibility for accurate and appropriate maintenance, operation and disposal, these are managed as separate assets and the relevant asset data is captured in the computer maintenance management systems (SAP).

# 3. LEVELS OF SERVICE

## 3.1 Stakeholder Requirements

Powerlink has a number of service levels derived from its strategic drivers; statutory authorities and our transmission licence and associated operating obligations, some of which are considered below as applicable to underground cables.

### 3.1.1 Safety Compliance

The fundamental requirement is for Powerlink to ensure underground cables are electrically safe in terms of their design, configuration and construction, and are operated in a way that is electrically safe. Other physical attributes of the underground cable asset, including integrity of the cable easement and signage must be managed to ensure a safety compliance outcome.

Of equal importance is to have safe work practices in place for the maintenance activities to ensure that Powerlink's target for zero accidents is achieved. To ensure this outcome, Powerlink uses a number of design and maintenance measures, some of which are listed below.

Design measures include:

- Compliance with the Electrical Safety Act, Section 4, Code of Practice for Works 2010, which covers the requirements for design and installation of underground electric cable systems. It specifies required cable depth, requirements for identification and record keeping, protective earthing of cables, mechanical protection of cables and cables separation.
- Location of cable terminations within securely fenced areas or at inaccessible heights on suitable structures.
- Implementation of adequate:
    - cable and termination structure earthing arrangements
    - lightning and switching overvoltage protection
    - location and safety signage
    - structural integrity
    - mechanical links.

Operation and maintenance measures include:

- Routine patrols and the annual review of patrol outcomes.
- Active application and use of Dial Before You Dig (DBYD) scheme.
- Routine earth sheath resistance measurement to ensure the appropriate cable earthing and insulation level.
- Earth grid injection test at transition sites or footing resistance measurement at transition towers.
- Effective asset information systems, particularly geospatial mapping and asset registers, in order to appropriately record the location of underground cable assets. These systems are used to advise staff and members of the public of potential electrical hazards associated with excavation activities.
- Annual review of the continuous current and fault current ratings.
- Monitoring of forced outage data to identify actions to improve underground cable performance where necessary.

As with all of Powerlink's assets and related work practices, there is a requirement to ensure overall compliance with all workplace health and safety legislation, translated into Powerlink's Safety Management Systems when designing, working in close proximity, maintain or switching underground cable systems.

### 3.1.2 Reliability of Supply

Powerlink ensures underground cables that are required to meet the long term needs of the network are maintained or replaced where indicated necessary through condition assessment to ensure the ongoing safe and reliable operation of the underground cables.

Powerlink has established a business process for obtaining outages that involves negotiation of a suitable time with regard to market impacts and customer impact (generators and direct connect loads). All planned outages are managed and co-ordinated by Network Operations in periods of low loads, where possible. Routine maintenance is reviewed by O&FS every two years to ensure only appropriate routine maintenance is undertaken, especially those tasks involving plant outages.

For unplanned outages, a business process and complementary system have been developed to enable review by the Technical and Network Services group of the root cause of underground cable outages, to enable the identification of actions or plans to improve reliability where required.

Underground cable performance is also analysed by monitoring the number of forced outages, number of notifications involving breakdown, number of DBYD enquiries and maintenance testing results captured within measurement documents.

To minimise the number of unplanned outages, Powerlink has undertaken significant effort to arrange feeder protection to allow the auto-reclose even on those feeders which incorporate a length of underground cables.

### 3.1.3 Compliance with National Electricity Rules

As part of network investment Powerlink is required to:

- Plan network development in accordance with the transmission authority, the Electricity Act and National Electricity Rules.
- Monitor the condition of all underground cables to provide safe, reliable electricity supply.
- Minimise the risk of actual loss of supply events.
- Meet the needs of our customers.

This is achieved through careful monitoring of load growth and network capability. Where the network capability is identified to be in need of further augmentation, various options are considered and an appropriate solution to meet the need analysed and planned. Where the investigation of future transmission line easements determines there are requirements to consider the use of underground cables to meet the reliability, quality of supply, resilience of the network or surrounding land use constraints, high voltage underground cables will be considered based on life cycle cost analysis performed on a case by case basis. In practical terms, high voltage underground cables are typically utilised in short lengths to overcome the impact on surrounding land use, particularly with regard to protected vegetation and existing community infrastructure.

### 3.1.4 Customers and Connection Agreements

Powerlink is required to meet the terms of Connection and Access Agreements. Each connection agreement specifies the requirements of the particular customer with respect to the availability and reliability of the connecting assets. Forced outages are routinely analysed and those that relate to a Powerlink customer are reviewed with Network Customers group where there is a significant impact on the affected customer.

Powerlink's maintenance programs are also coordinated to occur in conjunction with shut down of customer plant or at times of lower load to minimise production impact or associated market impacts.

### 3.1.5 Environment Compliance

Powerlink has an obligation to comply with the Environmental Protection Act 1994 and other environmental legislation.

A significant environmental issue during project planning phases involves the management of magnetic fields on cable easements, as per the levels stipulated in ARPANSA guidelines. These aspects are managed through the application of appropriate route selection and cable design practices, in a similar manner to high voltage transmission lines.

During construction, the major impact on the environment involves the clearing of cable easement for construction and maintenance access. Powerlink employs bidirectional drilling and other available methods to minimise such impact. Powerlink has guidelines for vegetation that can be used on underground cable easements without impacting reliability of supply.

Another significant environmental issue with underground cables relates to the management of potential oil leaks from self-contained fluid filled cables. Powerlink has implemented routine inspection and testing programs to monitor this issue in conjunction with on-line monitoring of cable pressure and oil levels.

Compliance with environmental, planning and cultural heritage legislation is common across all Powerlink assets and is being applied to the underground cables.

# 4. LIFECYCLE MANAGEMENT

In order to achieve the best outcome for its stakeholders, Powerlink must optimise the asset's whole of life cycle cost, risks and benefits. This is the basis of Powerlink's asset management approach and involves the following:

- optimisation of the concept and the design process
- consideration of the asset's likely operating life and
- effective management of the asset's lifecycle through targeted maintenance, refurbishment, replacement and disposal activities.

This approach is often referred to as the Asset Life Cycle and includes three main stages:

- planning and Investment
- operation, maintenance and refurbishment
- end of life.

## 4.1 Planning and Investment

The Planning and Investment stage involves consideration of the various options available to achieve required forecast demand.

Once all the requirements are clarified and agreed upon and the majority of the easement known, specific project outcomes are defined, in order to:

- achieve the desired Levels of Service over the life of the asset
- ensure the expected or desired asset life is achieved
- optimise total lifecycle costs
- ensure the maintainability and supportability of the asset over its intended life
- comply with corporate and statutory environmental and safety requirements.

There are a number of asset management guidelines to ensure the underground cable system design meets all the requirements of future maintenance, operation and disposal of the cables in the most cost effective way ensuring minimal impact on safety and environment.

The final aspect of the Planning and Investment phase includes determination of the procurement method, contract, project and construction management, variations, testing, commissioning, production of "as built" documentation and final handover. The majority of HV underground cable systems are constructed using "turn-key" systems, although design of transition sites is usually done using internal resources.

## 4.2 Operation, Maintenance and Refurbishment

Once the underground cable system is constructed, tested and energised, the Operation, Maintenance and Refurbishment stage begins. Over the expected 40-50 year life of the asset, management policies and procedures must be in place during this phase to ensure all assets are operated within their technical parameters and continue to perform to their initial specifications.

Underground cables are not directly susceptible to the transient outages typically caused by severe weather conditions and/or wildlife. The cables are, however, very sensitive to the overheating caused by either overloading or changes in soil profiles along the cable route. These differences have to be catered for by the application of the appropriate hybrid circuit protection catering for both overhead and underground cable faults and by the appropriate operation and monitoring of the load on such circuits.

Underground cables forced outages will generally be of longer duration than those of overhead lines and the outage management system has to cater for this.

Powerlink has adopted Reliability Centred Maintenance (RCM) analysis of plant maintenance requirements which provides a framework for logically analysing the potential failure modes of plant, equipment and systems, as well as their likely effects and consequences.

### 4.3 End of Life

The End of Life stage is the point at which the underground cable requires condition assessment or other analysis to assess its capability considering its condition, performance, availability, reliability and supportability.

Powerlink considers that the age of an asset does not provide for automatic justification of its replacement. The condition assessment process includes an assessment of whether the underground cable system has reached its end of life state due to issues with capacity, capability or compliance.

The terms capacity, capability and compliance are used to broadly describe a number of specific issues (such as poor performance, new standards, rising fault levels and obsolescence) that may lead to asset reinvestment action. Where possible, underground cable replacement needs are coordinated with the load-driven capital works program. This is the most common approach used for the replacement of the underground cables located within Powerlink substations.

Where the analysis confirms an underground cable system requires replacement or disposal, a number of statutory regulations need to be met, primarily aimed at ensuring the environmental impact of disposed underground cable systems is minimised or diminished. Often additional safety precautions are required to ensure disposal is completed in a manner that is safe for the employees, contractors and the general public.

Due to the nature of underground cables and the proximity of their installation to the urban areas, it is unusual to be able to re-use the existing easement without causing significant impact on the public and functioning of other infrastructure. It is more probable a different cable easement will be used and thus to minimise both cost and any such impact, the old cables have to be secured, sealed and earthed and left underground. In such instances, the cables identification and records are maintained with DBYD.

# 5. ASSET MANAGEMENT DRIVERS

Asset management practices must consider all risk associated with the planning and investment, operation, maintenance and refurbishment and end of underground cable system life. This is intended to optimise the asset's operating life and whole of life cost. This can only be achieved by adopting an asset management strategy that incorporates a timely response to a range of internal and external factors, including:

## 5.1 Internal

- condition assessment process
- technical investigations
- data modelling and reporting
- underground cable ratings.

## 5.2 External

- emerging issues
- environment and duty
- change of legislation, standards or other requirements
- demand and energy consumption.

## 5.3 Condition Assessment Process

Underground cables typically deteriorate due to mechanical damage, thermal stress and any inherent material aging processes. They are particularly sensitive to overvoltage and/or voltage surges, as well as soil movement, erosion or soil disturbance. Condition assessment provides an indication of defective and deteriorated components and initiates further investigation and analysis of the data. This determines the level of component deterioration, the holistic condition of each underground cable system and the potential options to achieve best asset reliability.

The condition assessment process for underground cable assets involves the analysis of physical condition, maintenance data, operational records, engineering data and technical investigations to develop a holistic view of the condition of the asset. The model below demonstrates how these inputs contribute to the condition assessment process.

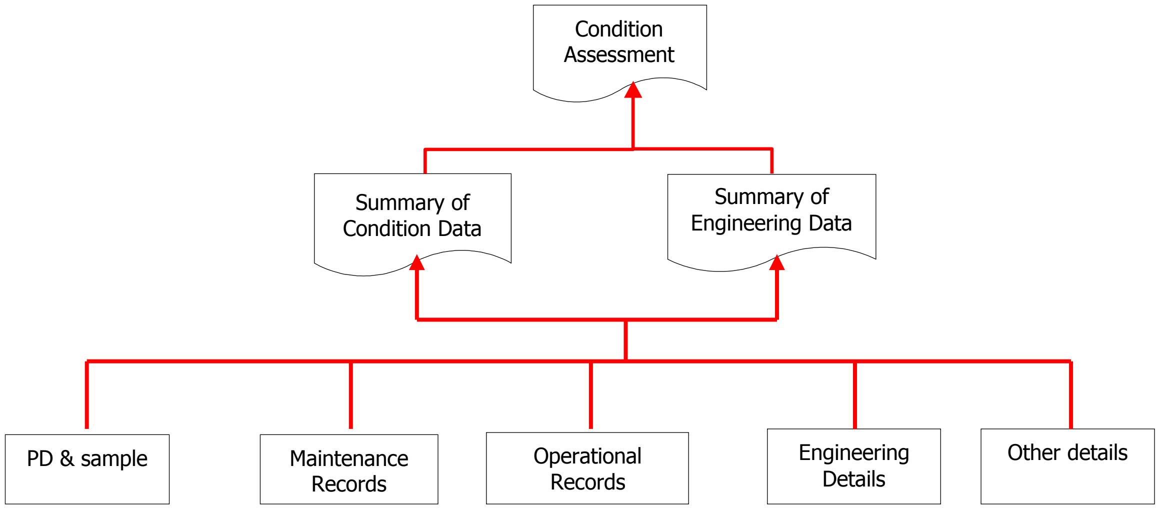


**Figure 2 - Input contribution to condition assessments**

### 5.3.1 Condition Assessment Report

The Condition Assessment Report for an underground cable asset is the product of the Condition Assessment Process. The Condition Assessment Report will take the engineering and condition data and apply analytical techniques, modelling, expected future performance criteria and probabilistic evaluation to determine the decision criteria for the condition assessment. This activity will be managed by HV Asset Strategies and may include consultation with design groups and the respective maintenance service provider for the asset.

The objectives of the Condition Assessment Report are to

- determine the condition of the asset with respect to the decision criteria.
- validate or recommend changes to the maintenance strategy of the asset based on condition.
- determine the possible options for replacement/refurbishment/decommissioning of the asset if required.

## 5.4 Summary of Condition Data

The Summary of Condition Data will collate information relating to the known underground cable condition and performance. This could include:

- cable sample tests for water and electrical treeing and/or termite damage
- partial discharge measurement on cable, cable joints and/or cable terminations, accessories and cable system components
- condition assessment reports
- forced outage history
- preventive and corrective maintenance reports and plant service history.

This activity will be undertaken by HV Asset Strategies and design groups and the respective maintenance service provider.

### 5.4.1 Data Modelling

The SAP maintenance system model for underground cable assets forms a part of the condition reporting process between maintenance service providers, Technical and Network Services group and the HV Asset Strategies Team. The data is audited on an annual basis by maintenance service providers themselves as well as by the Technical and Network Services group. This includes a review of associated maintenance costs and root causes of defects and based on these and other inputs the overall strategy may be modified if required.

## 5.5 Summary of Engineering Data

The Summary of Engineering Data will collate information relating to the designed performance of the asset. This could include electrical, hydraulic and layout design information and easement information. It will also include consideration of material performance in the service environment, design vulnerabilities and assumptions, historical performance of similar assets and industry experience. This activity will be undertaken by HV Asset Strategies and design groups and may include distributed temperature measurements, actual current and voltage measurements and analysis, fault current capability assessment, over-voltages, etc.

### 5.5.1 Technical Investigations

To support the underground cable asset strategies, technical specialists are engaged from time to time to assist with the investigation and resolution of site, technical and or asset performance issues.

Investigations can be initiated by a task request for internal specialists or a commercial arrangement with a subcontractor or industry specialist. These activities include termite management, earthing, tree specialist, land development near and at cable easement, circuit performance, component performance, special investigations, water and electrical treeing and new technology.

### 5.5.2 Underground Cable Ratings

Powerlink reviews and calculates underground cable ratings for the majority of Powerlink feeder type cables. As the cable ratings are dependent on the condition and types of soil surrounding it, the re-calculation of the cable ratings is triggered on a case by case basis where there is a significant change (e.g. major road extension).

## 5.6 Emerging Issues

### 5.6.1 Double Circuit Reliability

The HV Asset Strategies Team, which is responsible for the strategies for underground cables, is continuously looking at technology and methods to monitor cable condition, protection of hybrid feeders (overhead lines containing underground sections) in such a way to minimise double circuit outages and their outage duration. Whilst underground cables have a very limited exposure to the environment, there is a number of overhead transmission line double circuit outages caused by lightning and/or bird activity. To minimise the impact of these, Powerlink has adopted and is implementing use of “smart” protection relays on all hybrid feeders (transmission lines containing underground cable section/s) to allow use of automatic reclose when the detected faults are in the overhead section.

The automatic reclose is disabled if the fault is detected in the underground section as transient faults on underground cables are very rare. In this way, the outage duration is reduced where possible and at the same time the integrity of underground cables is not comprised.

High voltage underground cables installed in Powerlink substations are included in the protection zone of the power transformer current differential protection. In the case of cable fault, the power transformer will trip and this event will be investigated as a power transformer fault at the first instance.

To have immediate and clear indication of a cable fault, additional current transformers have to be installed between cable and power transformer. Powerlink has installed toroidal current transformers suitable for the installation on power cables up to and including 145 kV cables.

### 5.6.2 Distributed temperature sensors (DTS)

Powerlink ensures all cable installations outside substations include fibre optic cable which can be used with DTS equipment. DTS provide temperature profile of the cable along its route. It can be used to provide the indication of critical points on cable route, changes of conditions on cable route (additional soil layer, for example) and if used on a line can provide capabilities for increased cable rating. From time to time Powerlink uses portable DTS units to check existing cables which have fibre optic cables installed.

### 5.6.3 Climate Change Adaption

Climate Change adaptation dictates that the resilience and durability of infrastructure needs to be determined, and that managers have a solid understanding of the conditions that the asset will face over its useful life.

The impact on any individual asset will need to be determined and assets may require modification to adapt to meet changes in environmental conditions.

Projected possible impacts of climate change in Queensland include:

- increase in number of days over 35$^{o}$C
- changing annual rainfall and increased evaporation
- increase in severe storm events and flash flooding
- more frequent and severe droughts and increased fire risk.

The major impact on underground cables will be caused by:

- change in annual rainfall and increased evaporation (thermal soil resistivity will change)
- more frequent and severe droughts and increased fire risk.
- increase in severe storm events and flash flooding (this will have to be considered during the cable easement selection process).

# 6. ASSET MANAGEMENT ACTIVITIES

Electricity transmission assets have a relatively long expected operating life over which a range of asset management activities will be conducted, as outlined in the following sections.

## 6.1 Planning and Investment

At the Planning and Investment stage, the range of underground cable augmentation, and replacement needs are considered and coordinated to ensure an optimum program of overall underground cable investment. An essential requirement for initiation of underground cable replacement is to establish the ongoing requirement for the asset to meet the long term needs of the network. Hence, there is an imperative for asset reinvestment planning to be structured to reflect future network needs and also for network planning to be undertaken with cognisance of the underlying conditions of the asset.

The approach to planning and investment also involves ensuring the proposed configuration of the underground cable asset, established through forums that steer network investment decisions, meets the high level Planning and Investment objectives discussed in Section 4.

## 6.2 Operation, Maintenance and Refurbishment

### 6.2.1 Operation

Powerlink has established a business process for obtaining high voltage network outages that involves negotiation of a suitable time for planned outages with all interested parties (generators and customers). While underground cable faults are rare, their outages can be lengthy. A key component of underground cable management involves ensuring easy and quick access to trained cable jointers as well as immediately available maintenance spares for fault restoration. A number of other asset management initiatives have been implemented for the operations and maintenance of underground cables, identified below:

- Powerlink has established a standard cable specification for use in substations up to and including 33 kV voltage level and is working to standardisation for 145 kV rated cables to ensure cable spares with a short shelf life are readily available.
- Powerlink owns and maintains emergency restoration structures that can be also deployed in the case of underground cable failure. These are accompanied by contingency plans for all major underground cables.
- All planned outages are managed and co-ordinated by Network Operations in periods of low loads. The routine maintenance is reviewed every two years to ensure only appropriate routine maintenance is undertaken, especially those tasks involving plant outages.

The underground cable performance is also analysed by monitoring the number of forced outages, number of notifications involving breakdown, number of DBYD enquiries and maintenance testing results captured within measurement documents. Since Powerlink's underground cable population is still relatively small, the analysis is done on a cable by cable basis. The number of outages caused by failure/s of underground cables is very small, but the impact is often high and repair/ replacement can be lengthy.

### 6.2.2 Maintenance

Maintenance strategies for underground cables are developed using Reliability Centred Maintenance (RCM). RCM provides a rigorous and auditable analysis framework for identifying only those maintenance tasks that are applicable and effective in managing possible failures. RCM analyses are undertaken by facilitated review teams of technical experts and field personnel with the greatest knowledge of the assets being analysed. RCM also identifies failure modes that cannot be dealt with effectively by maintenance alone and thus require other approaches to deal with them. This ensures that only practicable, achievable and effective maintenance tasks are adopted.

RCM identified the following cable subsystems:

- cable system components (cable, terminations, joints, earthing, optic fibre temperature monitoring system, link boxes, earth sheath)

- condition monitoring and protection devices, if any (pressure transducers, distributed temperature monitoring, communication equipment, etc.)
- oil system (oil tanks, pressure meters, pipe work and valves) – for Self-Contained Fluid Filled (SCFF) cables only
- transition/support structures (transition and support structure, surge arresters and counters)
- cable pits (sump pumps, waterproofing, doors, security, maintainability), if any
- easement (land-slides, land use changes, signage, vegetation).

Each cable system is managed by managing its major component groups as identified above.

Central to the application of the RCM model is the timely collection of information on the condition and performance of the asset. To achieve this, Powerlink's underground cables are configured into Built Sections, each circuit being an individual Built Section and asset value.

To accommodate replacement of a single core, Built Sections are further broken into cable cores where applicable and their technical details are captured separately.

At the higher voltages (typically 66 kV and above), the cable terminations are modelled separately either as part of the relevant substation or transition site structure. Transition sites are also modelled separately.

Powerlink classifies maintenance as described below.

#### 6.2.2.1 Routine/Scheduled Maintenance

Routine/scheduled maintenance is undertaken when hidden failures exist in underground cables or associated equipment that must be addressed through various forms of routine activity – typical routine activities for underground cables are cable patrols, visual inspections of all cable system components (Level 1); close visual inspection and electrical test of earth sheath, surge voltage limiters and infrared examination of cable terminations (level 2); as well as monitoring of oil pressure in the cables (although this is mainly done using remote interrogation).

#### 6.2.2.2 Preventive Condition Based Maintenance

Preventive condition based maintenance usually evolves out of routine maintenance or inspection, where a technician notes that an underground cable or its associated equipment is operating out of tolerance and requires attention at some point in the future. Typical condition based activities for underground cables would involve investigative digging to ascertain the long term impact and/or to establish root cause.

Condition based maintenance activities are generated from routine inspections and tests, condition assessments or other information sourced from the physical condition of the underground cable system or its components. Condition based maintenance activities can include:

- line patrols after flooding, storm activity or bushfires or surveillance
- condition based un-covering of the part of the cable or joint for visual engineering inspection
- additional thermal imaging of cable terminations
- thermal imaging of the cable joints
- partial discharge measurement on the cable joints or terminations
- thermal distribution measurements along the cable length after significant changes in the environment along cable route (for example soil piling)
- sampling of cable or cable sheath
- termination replacement.

#### 6.2.2.3 Emergency Corrective Maintenance

Emergency corrective maintenance can occur at any time, and involves faults that must be attended to immediately to preserve human safety, manage environmental issues or return of underground cable to service to reduce the impacts of network outages on our customers, such as is cable termination replacement.

 

#### 6.2.2.4 Deferred Corrective Maintenance

Deferred corrective maintenance involves faults on underground cables that are not urgent and can be prioritised and aligned with other work in the future to minimise maintenance costs and effort, such as a slow oil leak from a termination point.

#### 6.2.2.5 Maintenance Support

Maintenance support tasks are those activities which are related to the ongoing maintenance and operations of the plant, but which do not specifically involve the plant itself. Examples include carrying out fault analysis and periodically reviewing each or some of the underground cables to consider changes in operational duties (loading, average ambient temperatures, fault level, etc.). Maintenance tasks resulting from these investigations and reviews are documented as quality procedures and incorporated into the policies, procedures and secondary documentation for the different asset groups. Typically for lines, the loading of lines is analysed and the input goes into the ratings documents. The fault level and fault current capacity of cable earth screens are analysed and the recommendations are submitted where the potential encroachments are noted.

The underground cable maintenance management model is based on the following maintenance activities.

**Table 2 - Asset Maintenance Types**

| Maintenance Type | | Activity | Frequency |
|---|---|---|---|
| Preventative Maintenance | Routine Preventative Maintenance | Underground cable patrols (ground patrols) – not applicable to cables located within substations | Monthly |
| | | Underground cable Level 1 Maintenance | 6 monthly |
| | | Underground cable Level 2 Maintenance<br>• Cables with extruded insulation located in substations.<br>• Fluid filled cables located in substations.<br>• Fluid filled cables not located in substations.<br>• Cables with extruded insulation not located in substations | <br>4 yearly<br>2 yearly<br>Annually<br>Annually |
| | | Dial Before You Dig (DBYD) | Continuously as per inquires |
| | | Transition site maintenance | Annually |
| | Condition Based Maintenance | Cable termination replacement | Based on condition and type of cable termination. |
| | | Distributed temperature measurement | Based on change of easement conditions |
| | | Cable joint replacement | Triggered by joint damage, low reading of earth sheath resistance or by Partial Discharge (PD) indication |
| | | Partial discharge measurement on cable, cable joints and/or cable terminations | Based on condition. |
| Corrective Maintenance | Emergency Corrective Maintenance | Cable termination explosive or non-explosive failure.<br>Significant loss of oil pressure causing either alarm or trip of cable circuit. | |
| | Deferred Corrective Maintenance | | |

### 6.2.2.6 Underground Cable Measuring Points

Powerlink has established measuring points for underground cables. These will be directly related to the Level 2 Maintenance and will enable trending of the test results.

Maintenance service providers are providing information on underground cable condition in the form of notifications and work orders. These records as well as all patrols, Level 1, and Level 2 internal records are audited on an annual basis by O&FS. From the results of the review, further actions are considered and discussed with the maintenance service provider. The review includes data from the Forced Outage Database (FOD) to assess the exposure of each individual cable to faults and/ or surges caused by faults.

Powerlink has adopted the protection philosophy which allows automatic reclose on the feeder containing underground cable/s if "smart" relays are used to ascertain the fault location is not in the underground cable/s section/s. This protection philosophy, commonly used worldwide can, however, result in a higher number of switching surges and therefore impact on cable condition. This is why the review of the FOD is so important.

#### 6.2.2.7 Singular Asset Management

Underground cable assets may be classed as singular if increased reliability is required from the asset to meet a commercial or business driver.

Assets identified as requiring increased reliability fall outside the scope of the normal asset management model. These assets require condition assessment every five years in addition to the normal Underground Cable Maintenance Strategy. Advancing defect rectification is required to ensure desired reliability is achieved.

The underground cable population includes high voltage cables of various voltage levels (11, 22, 33, 66 kV) which are typically short lengths and in most cases connected to the power transformers. Problems with these cables can also lead to transformer failure, compromising substation integrity. This is why, despite their relatively small asset value, they are considered higher risk items.

#### 6.2.2.8 Significant Failure Zones

Underground cables run through areas of diverse land usage. They can also cross major roads, highways, public car parks and/or creeks, rivers and other underground utilities. These are all managed through the DBYD enquiry process. The cable routes are patrolled once a month to ensure cable markers are in place and there have been no unauthorised activities.

### 6.2.3 Refurbishment

Improvements can be made through Refurbishment to bring the asset up to current standards and/or to meet improved safety or operational requirements. Examples of such activities include:

- upgrade/modification of cable earthing
- upgrade/replacement of the underground cable signage
- upgrade of lightning protection
- additional installation of any condition monitoring devices (pressure transducers) or condition monitoring systems
- additional vermin or termite protection installation.

## 6.3 End of Life

An underground cable has as an expected service life of 40-50 years and is monitored for defects throughout its life. Some components get replaced throughout the technical life of underground cables. Despite this, there is a point where a condition assessment for an underground cable asset identifies that the cables have reached their technical end of life.

The technical or economic end of life of an underground cable is when the asset no longer meets minimum technical requirements and presents an unacceptable risk to the business or is uneconomic to retain.

The following options should be considered:

- cable replacement
- cable disposal.

To make the correct decision regarding these options a number of additional factors need to be considered such as:

- present and future load flows and network topology
- existing easement width, conditions and access for works
- level of difficulty involved in obtaining a new easement for the cable route
- condition of underground cable and the technical or cost implications associated with replacement
- maintenance costs.

The decision making process requires data associated with the asset to be gathered well in advance of the anticipated major deterioration of the asset to ensure that all options remains technically feasible for the asset (typically 7 years for underground cable condition assessments).

### 6.3.1 Underground Cable Replacement

Underground cable replacement projects will be proposed for deteriorated underground cable assets which have reached end of life.

The replacement of an underground cable asset should consider:

- replacement with an underground cable from the standard size range of equal to or greater capacity
- improved cable monitoring for ratings and security such as inclusion of DTS technology
- update of design requirements considering current standards and environmental factors.

### 6.3.2 Underground Cable Disposal

Disposal of underground cable assets is considered where they are deemed as not required in the current and future network topology and have significant maintenance costs. Once these have been decommissioned and are non-operational, they may be demolished.

To minimise the cost impact of demolition, assets can be de-energised and made safe in order to delay the cost of disposal to an appropriate time. This may also have the advantage of preserving the easement if circumstances change and another underground cable is required. To de-energise and make safe an underground cable asset, the asset shall be electrically disconnected from the network with cable terminations removed; the ends of all cables shall be capped to reduce further deterioration. In the case of SCFF cables, as much oil as possible shall be removed prior to capping the cables. This does not however eliminate the environmental risks on SCFF cables, as future oil leaks may occur as the cable degrades over time. Some maintenance will still be required to ensure the cable does not become exposed, is marked appropriately and has not caused any environmental damage.

Decommissioning and removal of the asset in a timely fashion eliminates the ongoing environmental risk and eliminates the need for further expense on the asset. The timing for removal should consider: exposure to the public, costs of maintenance and available resources.

Asset Disposal for underground cables has five main stages with the first three to be completed under the same project.

1. removal of cable terminations, structures and associated equipment
2. removal of as much oil as possible in SCFF cables
3. terminating the cable underground and capping the cable ends to reduce further deterioration
4. removal of the cable and cable joints from the ground
5. rehabilitating the site and access to reduce environmental impacts.

A condition assessment shall be carried out on selected components (terminations and cables etc.) that are disposed of to provide historical condition information.

# 7. EMERGENCY RESPONSE AND NETWORK SECURITY

One of the major advantages of the underground cable usage in the harsh climate areas such as Queensland is they are less susceptible to the impact of cyclones and natural disasters. The major impact on the cables during such events will be the exposure to over-voltages, caused by overhead line trips and automatic reclose.

Due to easement constraints, diversity of underground cable routes is typically not achievable for double circuit underground cables. Considering the prolonged repair times for underground cable faults (minimum 7 days), there is a requirement to develop and maintain emergency restoration plans for major 275 kV cables. These will involve construction of a temporary overhead line if required and deployment of emergency restoration transmission line structures.

# 8. SUPPORTING ACTIVITIES

## 8.1 Risk Management

To successfully manage Powerlink's underground cable assets, it is necessary to identify and manage a range of hazards and risks. This is carried out consistent with the Powerlink Queensland Risk Management Charter.

The following tables summarise the identified nominal hazards, associated risk levels and their corresponding control measures.

**Table 3 - Identified Hazards and Control Measures**

| Technical Issue Related Hazards | Residual Risk | Risk Control Treatment |
|---|---|---|
| Fault levels rising beyond ratings resulting in catastrophic failures | Moderate [E5] | • Annual review to determine fault levels<br>• Initiation of project definition works if identified |
| General deterioration resulting in low reliability | Significant [D5] | • Design standards<br>• Equipment strategies for selection of hardware<br>• AM Policies and Procedures for maintenance<br>• Condition and asset assessments to determine viability of plant<br>• Initiation of project definition works if required |
| Technical support and jointing skills diminishing such that the cable cannot be successfully repaired | Significant [D5] | • Upkeep of identified skills training<br>• Proactive discussions with manufacturer to determine beginning of obsolescence<br>• Initiation of project definition works if required |

**Table 4 – Performance Related Hazards and Control Measures**

| Performance Related Hazards | Residual Risk | Risk Control Treatment |
|---|---|---|
| Catastrophic Failure of Equipment | Significant [D5] | • Maintenance procedures<br>• Equipment strategies<br>• Design standards<br>• Emergency response procedures |
| Incorrectly Performed Maintenance by MSP | Moderate [D4] | • Maintenance rocedures |

**Table 5 – Other Associated Hazards and Control Measures**

| Other Associated Hazards | Residual Risk | Risk Control Treatment |
| --- | --- | --- |
| Lightning strikes | Moderate [E4] | • Design Standards |
| Bushfire | Low [F4] | • AM Policies and Procedures |
| Flood | Low [F4] | • AM Policies and Procedures |
| Acts of Theft and Vandalism | Moderate [E4] | • AM Policies and procedures<br>• Design Standards |
| Exposure to EMF | Moderate [B2] | • Design Standards<br>• AM Policies and Procedures |
| Working at Heights | Moderate [D3] | • AM Policies and Procedures<br>• Use of elevated work platform or appropriate scaffolding<br>• Transition Sites |
| Unauthorised activities along the cable route | Moderate [B2] | • Definition and registration of underground cable easement wherever possible<br>• Maintenance of accurate cable route records with local city councils and/ or main roads<br>• Maintenance of accurate cable signage along the cable route<br>• Management of DBYD enquiries |
| Unauthorised access to transition sites | Moderate [D3] | • Design Standards<br>• Maintenance Policies and Procedures<br>• |
| Electric shock to personnel due to the increased sheath voltage | Moderate [D3] | • QEE Safe Access to High Voltage Apparatus<br>• AM Policies and Procedures<br>• Design<br>• Electrical Safety Rules |

## 8.2 Project Handovers

The construction of new underground cables, components replacement or cable replacements involves the interaction of design, construction, project management, material acquisition and strategies groups both within and external to Powerlink. The transition from the practical completion of the underground cable system to an operational asset and the maintenance of that asset requires the recording and communication of critical information and related data about the asset.

The Project Handover process has been implemented to provide the conduit for transferring design and construction information between the Designers, Construction Contractor and the Maintenance Service Provider. It further provides an opportunity for the Strategy Engineers to proactively seek feedback from Project Managers, the project team and stakeholders about the project and the project handover process to ensure that opportunities for improvement are implemented.

## 8.3 Equipment Spares

An annual review of underground cable spares will be performed to ensure that:

- the quality and quantity of underground cable spares are adequate and appropriate (consumables replaced)
- the storage practices and facilities of underground cable spares are satisfactory to ensure component life span is not compromised as a result of incorrect or inadequate storage practices
- spares have been provided for new assets and component changes
- consumables for cable joints/terminations to be reviewed every two years and replaced if required.

## 8.4 Human Resource Training

### 8.4.1 Training of Cable Jointers

Powerlink's underground cable asset base is small and would not provide sufficient work for dedicated cable jointers to maintain their competency. As such, Powerlink relies on agreements with third party cable jointers for some routine maintenance tasks, all emergency corrective maintenance and the majority of condition based work. These companies employ cable jointers who have jointing experience with cables at transmission level voltages.

### 8.4.2 Underground Cables Technical Training

The HV Asset Strategies and Technical and Network Services Teams will provide at least one underground cable technical training day annually to reinforce key concepts and strategies with service providers delivering across the asset lifecycle.

## 8.5 Documentation

The HV Asset Strategies Team will review relevant strategic Asset Management documents on a regular basis and promote the development of documentation and field guides to ensure underground cable strategies remain relevant and in accordance with good industry practice.

## 8.6 Strategic Linkages

The HV Asset Strategies Team will develop and maintain strategic linkages internally within Investment and Planning Division and groups external to the division to ensure a seamless integration of network topography is maintained.

Ongoing management of underground cable assets will require close liaison with Investment and Planning, and Primary System Design.

Investment and Planning shall be responsible for:

- Identification of requirements for new feeders due to the load increase.
- Assessment of requirements for use of HV cables as an alternative to overhead transmission feeders. Requirements for a new HV cable shall include full life cycle costs, based on a nominal 40 year life expectancy.
- Definition of the requirement such as cable continuous, emergency (cyclic) and fault current ratings based on predicted load flows and network configuration changes.

Primary System Design Group shall be responsible for:

- identification of requirements for HV cables within Powerlink substations
- identification of the cable routes within substations
- cable specification, layout design and cable ratings calculation
- provision of asset data
- removal and disposal of redundant cables
- design of transition sites.

Channels of active communication are maintained with other Transmission Network Service Providers through Australian CIGRE B1 panel for insulated cables which provides access to discussion forums for work delivery protocols such as cable earthing, reduction methods for EMF, experience with DBYD, factory and commissioning tests, new materials for cables and any other new technology.

# 9. ENVIRONMENT AND SAFETY

## 9.1 Environment

The design and implementation of underground cable maintenance strategies will incorporate Powerlink's Environmental Policy. This includes the use of environmental risk assessment processes to identify risks and to appropriately manage the risk.

## 9.2 Safety Management

The design and implementation of underground cable maintenance strategies will incorporate Powerlink's Safety Management System WHS-P&C–STD-A1955230. This includes the use of risk and hazard management processes to ensure safety or workers, safety of the public and the safety of plant and equipment.

# 10. FORWARD PLANNING

A 10-year Asset Management Plan is prepared by the Network Integration Team based on Area Plans, outlining capital projects by type, location and expected completion date as well as operational projects for major components.

All routine maintenance plans are entered into SAP by built section number to ensure automatic generation of work orders. The Maintenance Service Providers shall prioritise all notifications 12 months in advance assigning action by end dates for all high priority work.

# 11. DISTRIBUTION LIST

| Internal | Contact details |
|---|---|
| ☒ Investment and Planning | Executive Manager Investment and Planning<br>Group Manager Strategy and Planning<br>Group Manger Portfolio and Business Management<br>Main Grid and Controls Manager<br>HV Asset Strategies Manager<br>Network Integration Manager<br>Senior Lines Strategies Engineer<br>Senior Network Strategies Engineer |
| ☒ Infrastructure Delivery and Technical Services | Group Manager Infrastructure Planning<br>Group Manager Infrastructure Delivery<br>Group Manager Infrastructure Technical Services<br>Group Manager Infrastructure Management Systems |
| ☒ Operations and Field Services | Group Manager Technical and Network Services<br>Group Manager Field Services<br>Group Manager Specialist Services<br>Group Manager Network Operation Services |