Transgrid

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Underground Cables Renewal and Maintenance Strategy

AMS Asset Class Strategy

2020/2021

Document Control					
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Table 1 – Change from previous version

Revision no	Approved by	Amendment
9	Andrew McAlpine Head of Asset Management	Document now exclusively for prescribed assets (non-prescribed population statistics and commentary removed). Formatting update 2021 calendar review.
8	Lance Wee Head of Asset Management	Formatting update 2020 calendar review. 132 kV Cables and Below added to Section 5.
7	Lance Wee Head of Asset Management	Formatting update 2019 calendar review. New assets added in 2.4 Asset Overview Asset Management Strategy and Objectives has been replaced with Network Asset Strategy. Line of sight realigned accordingly. 50-year OPEX forecast removed. Asset Management Stagey and Objectives has been replaced with Network Asset Strategy – Asset Management System Boundary, KPI's Overarching business objective and Asset Strategy objectives updated.
6	Lance Wee Head of Asset Management	Formatting update 2018 calendar review.
5	Lance Wee Group Manager/Asset Management	Review and update to deliver the Business Plan and further enhance the strategy. Updated to reflect change in company structure and group titles. References updated
4	Lance Wee Group Manager/Asset Strategy	Formatting Update.
3	Lance Wee Group Manager/Asset	Review and update to deliver the 2016/17 Business Plan and further enhance the strategy.

Revision no	Approved by	Amendment
	Strategy	Significant revisions made due to the change in template
2	Lance Wee Group Manager/Asset Strategy	Review and update to deliver the 2015/16 Corporate Plan and further enhance the strategy.
1	Garrie Chubb Group Manager/Asset Performance	Updated to reflect the continual improvement in the 'top down' approach for the line of sight to the Asset Management Strategy and the Corporate Plan and an enhanced description of the asset management decision process and the strategic initiatives to be undertaken.

A printed copy of this document may not be the current version. Please refer to the Wire to verify the current version.

Executive Summary

TransGrid's underground cables provide transfer of electricity to the Sydney CBD. Repairs and investigations are costly, time consuming and disruptive as the cables are mostly in public roads. Being 'invisible' to the public makes the cables prone to damage by public interference.

Asset Review

TransGrid has 15 high voltage cables 132 kV and above, including internal substation connections. Whilst small compared to the overhead network, TransGrid cables represent a disproportionate portion of the asset base. Cables represent about 0.6% of the total route length but are approximately 13% of the circuits by value in the RAB. The prescribed cables are located within the Sydney region. A breakdown of cable assets is shown below.

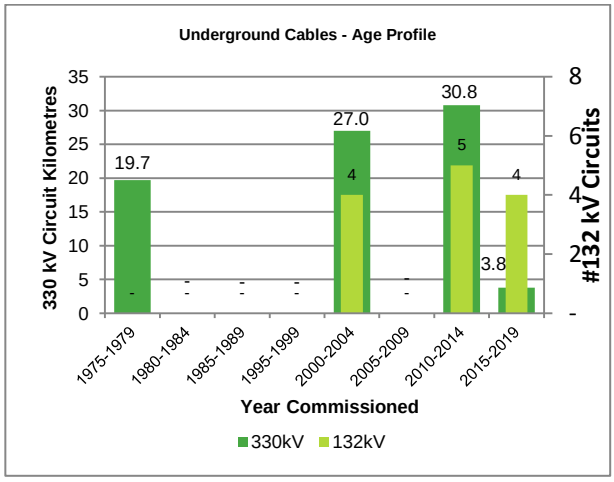


Figure 1 – Underground Cables age/circuit profile

Achievements

Fibre Sense monitoring installed on Cable 42. This enabled patrols on Cable 42 to be reduced by two thirds whilst providing continuous monitoring for rogue activity

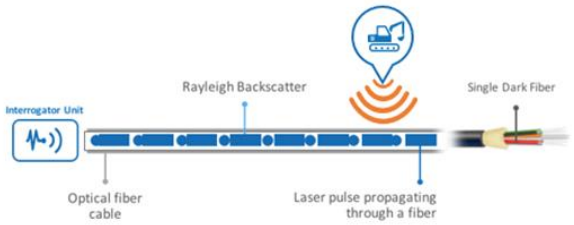


Figure 2 – Fiber Sense Monitoring

Challenges

Members of the public digging in the vicinity of TransGrid HV cables damaging the cable assets without authorisation.

Achieving cost reductions and efficiencies with an aging asset base.

Managing issues on Cable 41 as it approaches end of life.

Developing strategy for self-contained fluid filled cables (Cables 41 and 42) after manufacture support finishes.

Controlling threats from major infrastructure works near existing cables (e.g. Sydney Metro).

Initiatives

Expansion of Distributed Acoustic Sensing onto Cables 43/44, 39 and Powering Sydney's Future.

Contents

List of Tables

List of Figures

1. Foreword

1.1. Foreword

This document defines the renewal and maintenance strategies for TransGrid's underground cable assets. In doing this it applies the overarching Network Asset Strategy, and relevant Lifecycle Strategies. This strategy document covers all prescribed underground cable assets owned and maintained by Transgrid. Non-prescribed assets are excluded from this strategy document.

The document identifies the emerging issues with TransGrid's underground cable assets, and details the renewal and maintenance initiatives to be implemented in response to these issues. The output of the strategy is the asset management program of works, which is derived via distinct paths as follows:

The renewal and disposal initiatives are considered through the Prescribed Capital Investment Process and managed through the Portfolio Management group, which then which then leads to the resource-optimised capital works program.

The maintenance initiatives directly drive the maintenance regimes which are detailed within the relevant Maintenance Plan. The maintenance plans are then resource-optimised through TransGrid's Enterprise Resource Planning (ERP) system, Ellipse and supporting applications such as TRAC.

The population reviews and strategies in this document cover prescribed assets only for a five year period from December 2021. Non-prescribed assets are covered in Non-prescribed Renewal and Maintenance Strategy.

1.2. Overview

Key updates in this 2021 revision have been made in alignment with changes in the asset base:

- Upcoming Powering Sydney's Future commissioning in Q4 FY2022 – Cable 41 being operated at 132 kV
- Notification from Sumitomo that SCFF cable and accessories will no longer be available for after 2028. Orders need to be placed by 2023.
- Inclusion of RP3 submission :
  - Underground Cable Capital Spares
  - Cable Condition Monitoring System Renewals.

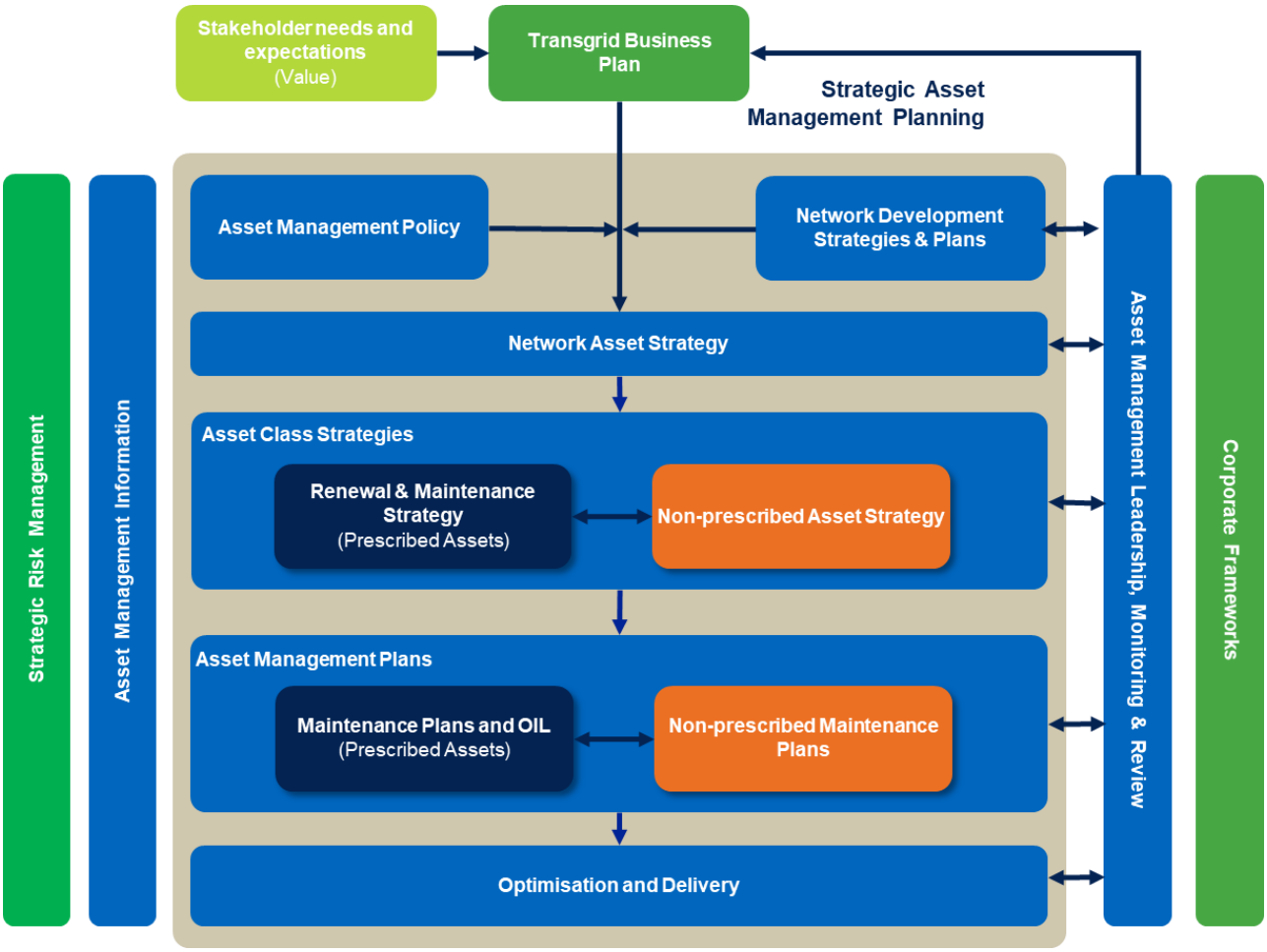
As asset management of the underground cables are considered unique in that they represent a small volume but high value asset, they have been excluded from the Repex model for reasons outlined in Section 6.1.3.

2. Context and Background

2.1. Relationship to Asset Management Systems

This Renewal and Maintenance Strategy (RMS) document is one of several that comprise the Asset Management Strategies within TransGrid's Asset Management System. This document sits below the Network Asset Strategy document as shown in Figure 3.

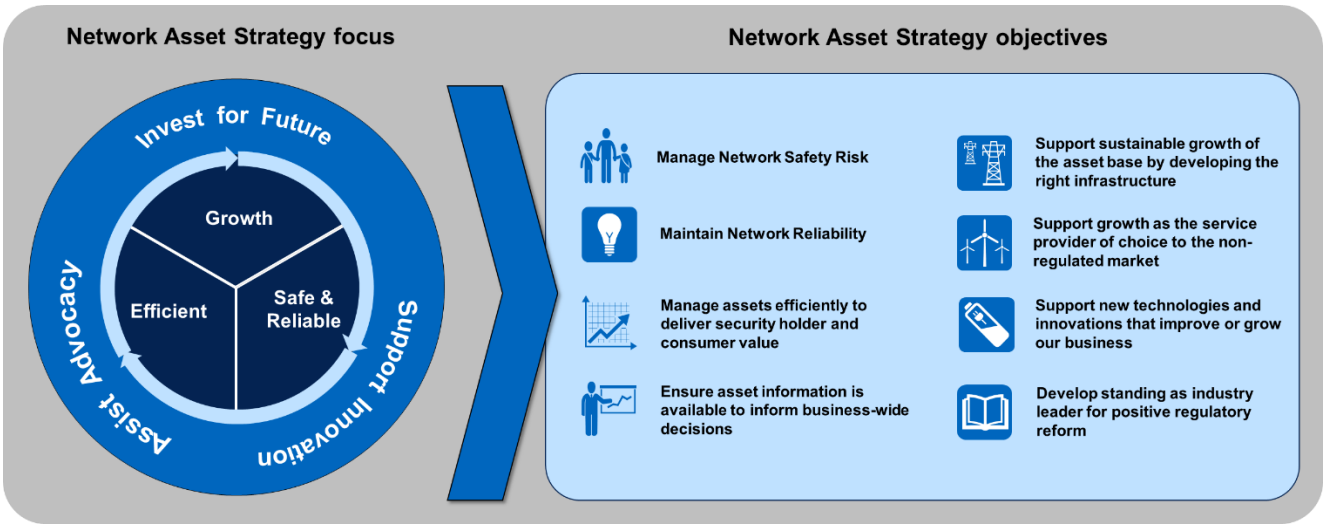
Figure 3 – Asset Management System Hierarchy



2.2. Asset Management Line of Sight

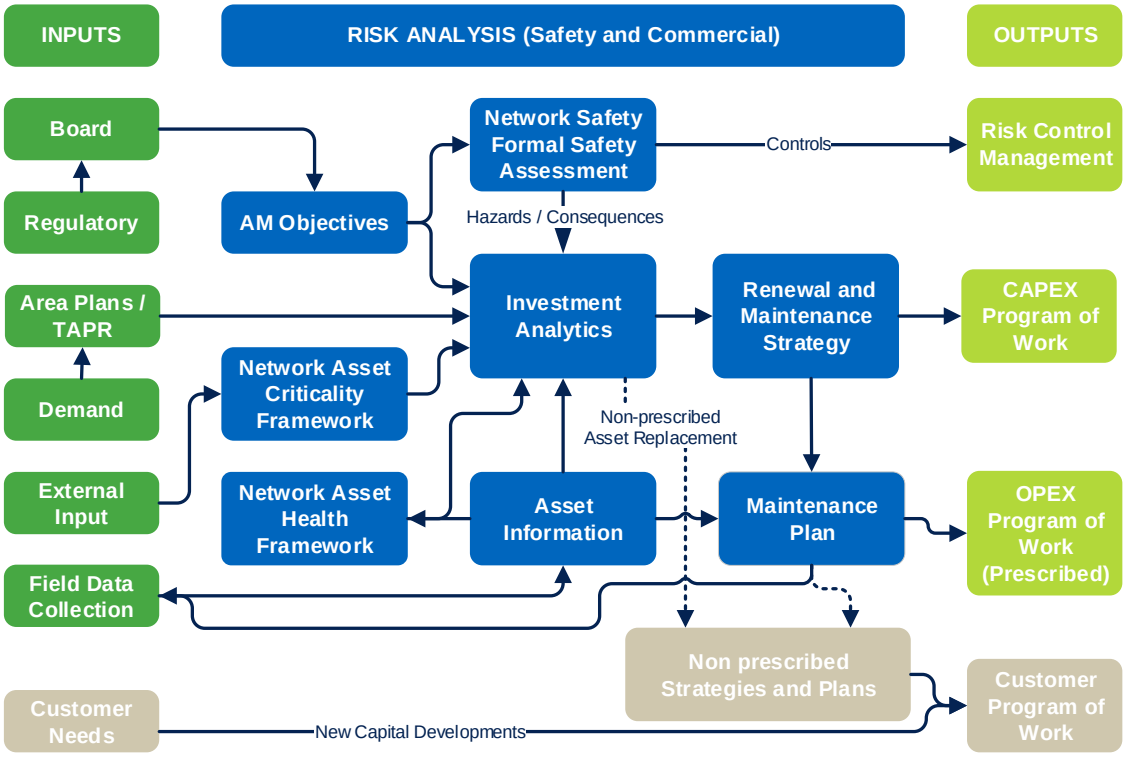
The renewal and maintenance strategic initiatives set out in this document support the achievement of the strategies set out in the Network Asset Strategy. The strategic alignment of the initiatives in this document to the Network Asset Strategy is based on meeting its strategic themes.

Figure 4 – Asset Management Strategy Key Themes



2.3. Renewal and Maintenance Process Overview

Figure 5 – Investment Development Framework



2.4. Asset Overview

2.4.1. Scope of Assets

The following assets are considered within the scope of this strategy:

- 330 kV underground cable assets, including pilot and optical fibre cables associated with these cables.
- 132 kV underground cable assets; this includes short lengths of 132 kV cables within Haymarket, Beaconsfield and Rookwood Road substation boundaries.
- Cable civil assets such as bridges, tunnels and structures.
- The 11 kV supply cables to Lower Tumut Switching Station, fed from Talbingo Zone substation.
- The following underground cable assets are outside the scope of this strategy:
    - Short lengths of cable energised at 66 kV, 33 kV and 11 kV which in general, though not exclusively, run within substation boundaries. These cables are covered by the Network Renewal and Maintenance Strategy – Substations.
    - The Gas Insulated Lines at Beaconsfield are not considered cables and are also covered by the Network Renewal and Maintenance Strategy – Substations.
    - Optical fibre and pilot cables not associated with a HV underground cable asset.

2.4.2. Asset Base

TransGrid has a total of 81 km 330 kV and 4 km of 132 kV of prescribed underground cable circuit. Within substations there is an additional 10 132kV internal substation connections.

The Talbingo to Lower Tumut Substation 11 kV supply cables are also covered by this strategy.

Asset life may vary depending on the cable or contract specification. The standard nominal lives, which are used in RIN reporting and modelling, regardless of contracted values, are as follows:

- 33 kV and below: 30 years.
- 66 kV and above: 45 years.

A snapshot of the underground cable asset base is provided in Table 2

Table 2 – Asset Base

Asset	Year Commissioned	Operating Voltage	Circuit Length	Description	Nominal Lifespan
Cable 41 (Cable 26F upon 132 kV operation)	1979	330 kV	19.7 km	• Cable 41 is a Self-Contained Fluid Filled (SCFF) circuit that runs between Sydney South Substation at Picnic Point and Beaconsfield Substation in Alexandria. • Associated with Cable 41 is a short 330 kV tie cable of identical construction. The tie-cable connects the two outdoor switchyards at Beaconsfield. • Oil pressure alarms are via twisted pair pilot cable UPC160. 8 pair pilot cables UPC160A and UPC160B are used for alarms on the sealing ends at Sydney South and Beaconsfield. • An online oil pressure monitoring system was installed in 2016. This system provides differential pressure alarm functionality. • Associated with Cable 41 are two small lengths of tunnel.	45 years (40 years in specification)
Cable 42	2004	330 kV	28 km	• Cable 42 is a polypropylene laminated paper (PPLP) fluid filled cable circuit that runs between Haymarket Substation and Sydney South Substation at Picnic Point. • Associated with Cable 42 cable is a 4 km length of tunnel between Sydney Park, St Peters and Haymarket substation. • This cable is monitored by a Cable Monitoring System (CMS). The CMS receives pressure information from the stop/feed joints. A Distributed Temperature System (DTS) provides temperature along the route as well as dynamic rating capabilities.	45 years (40 years in specification)
Cables 43 and 44	2014	330 kV	16 km	• Cables 43 and 44 are cross-linked polyethylene (XLPE) circuits that run between Holroyd Substation at Greystanes and Rookwood Road Substation at Potts Hill. • A CMS is installed on this asset providing DTS and dynamic rating capabilities.	45 years (40 years in specification)

Asset	Year Commissioned	Operating Voltage	Circuit Length	Description	Nominal Lifespan
Cable 39	2019	330 kV	3.7 km	• A section or of Line 39 was required to be relocated to make way for the Western Sydney airport. The option chosen was an underground cable running alongside the airport boundary. It is a prescribed asset, but not on the Asset Base. • 3.7 km is the route length, two cable per phase, separated by 10 m. • 1600 mm^2 XLPE cable manufactured by Sumitomo. Parts were purchased so that the spare 2000 mm^2 cable and joints held for Cables 43/44 are compatible for repairs on this cable. • There is a fibre path via OPGW on Line 39 for DTS and optical fibre CT's installed at transition sites for protection purposes (auto reclose blocking).	45 years (40 years in specification)
Haymarket connectors	2004	132 kV	280 m total	• The Haymarket connectors are 4 XLPE circuits that link the transformers and reactor to the gas-insulated switchgear (GIS) within Haymarket Substation.	45 years
Beaconsfield Reactive Plant connectors	2012	132 kV	200 m total	• The Beaconsfield connectors are 4 XLPE circuits that link the reactive plant to the gas insulated switchgear (GIS) within Beaconsfield Substation.	45 years
Rookwood Road connector	2014	132 kV	70 m	• The Holroyd connector is an XLPE circuit that links the 132 kV shunt reactor to the gas insulated switchgear (GIS) at Rookwood Road Substation.	45 years
Beaconsfield No.5 Tx	2017	123 kV	70 m	• XLPE cable from the 132 kV side of No.5 Transformer to the North switchroom.	45 years
No.1 Talbingo Town 11kV	1971	11 kV	150 m	• Normally open. • Essential Energy connection point pole next to Talbingo Zone 66/11 kV substation.	30 years
No.1 Talbingo Transformer 11kV B CB	1971	11 kV	150 m	• Normal source of supply to Lower Tumut Switching Station.	30 years

Asset	Year Commissioned	Operating Voltage	Circuit Length	Description	Nominal Lifespan
No.1 Talbingo Transformer 11kV A CB	1971	11 kV	150 m	• Faulted – cut and buried in the field	30 years

2.5. Spares

Spares are items of serviceable equipment that are booked into and stored in TransGrid's storage facilities for maintenance and emergency response. This document does not cover inventory which may be held for project purposes.

TransGrid has purchased a range of strategic spare equipment to improve the organisations ability to restore supply and improve system security in a timely manner, following the major failure of an in-service unit.

Spares are only held for the 330 kV underground cables. The 132 kV cables have a lower probability of failure as they are entirely within TransGrid substations. The criticality of the associated plant is low enough that an 'order when required' policy suitable. Due to the short shelf life of XLPE accessories, holding spares would require significant ongoing costs disproportionate to the risk.

The spares strategy for Underground Cable assets, including required holding is described in the document 'Underground Cable Assets Spares Plan'.

3. Current Performance

3.1. Review of Previous Renewal, Disposal and Maintenance Strategies

This section discusses the performance of the current asset base.

3.1.1. Historical Expenditure

3.1.1.1. Renewal Initiatives

There were no renewal initiatives completed in FY2021.

3.1.1.2. Maintenance Initiatives

There were no maintenance initiatives completed in FY2021.

3.1.2. Review of Renewal and Maintenance Initiatives

3.1.2.1. Renewal Initiatives

There were no renewal initiatives completed in FY2021.

The Cable 42 CMS was replaced in April 2017. As noted in the previous Renewal and Maintenance Strategy the new individual wired alarms only go through to the local HMI, they do not make it through to SCADA. Rectifying this issue was planned to be addressed as part of the project close out process but this did not occur. Investigations undertaken under defect works found that works were apparently installed as designed, so not in accordance with the need statement. These issues will now have to be remediated under condition based maintenance.

3.1.2.2. Maintenance Initiatives

There were no maintenance initiatives completed in FY2021.

3.1.3. Review of Maintenance Program

Routine maintenance regimes are reviewed annually and are adjusted to minimise total cost including risk cost.

Cables 41 and 42 supply the Sydney CBD and surrounding area. The consequences of failure of these assets is catastrophic, impacting on the state's economy. Repairs on TransGrid's underground cables take considerable time and cost. The failure of Cable 43 due to external interference took five months to repair and cost approx. $5 million to restore, and this was in a benign location with cables in conduit.

External interference is considered a major threat to TransGrid's underground network. Route patrols are in place to mitigate this risk of interference and represents the greatest routine inspection and maintenance expenditure in underground cables. In an environment where funding is becoming further constrained, these inspections are continually being questioned. Patrols on Sundays were discontinued from January 2019. Analysis showed significantly fewer encounters with the public on those days. Further, the use of Distributed Acoustic Sensing (DAS) on line monitoring system on Cable 42 from April 2020 allowed the patrols on that circuit to be rolled back further (to two days a week).

There was an incident on Cable 43/44 in July 2020 where an NBN contractor attempted an unauthorised crossing in Parkes Street Guildford, on the one minor section with shallow installation of the ECC conduit. The contractor was in possession of the DBYD information, however the requirements as noted on the information were not adhered to. Due to the arrangement of ECC at this location there was a risk of asset damage. This area of Cable 43/44 is only patrolled on a weekly basis as most of Cable 43/44 is not installed in roads. The 25 MPa concrete ductbank would make this asset more resilient than the 14:1 sand/cement of previous assets, so would need less frequent inspection than the older assets.

Routine maintenance regimes were first established based on manufacturer recommendations, and then refined over the decades as TransGrid's experience with each asset type has developed through the asset lifecycle, with the maintenance regimes now reflecting the condition and risk for each asset.

In FY2021 defects were 40% higher than the annual budget driven by a subsidence event on Cable 41 and increased MetroGrid tunnel groundwater treatment plant defects. On an overall basis the budget was 18% underspent. This underspend was mainly due to condition based maintenance not being progressed as part of portfolio prioritisation between asset class and savings in the routine patrol inspection.

The prescribed maintenance spend of the FY2021 Maintenance Plan was as follows:

Table 3 – Transmission Line OPEX 2021FY

	Actual $	Budget $	Variance $
Routine	596,521	$795,769	199,249
Inspections	343,257	$363,219	19,963
Condition		$200,000	200,000
Defect	402,911	$286,000	(116,911)
Totals	**1,342,689**	**1,644,989**	**302,300**

3.1.4. Past Performance – Asset Management Performance Indicators

In November 2021 the Network Asset Strategy was issued. This document introduced new KPI's. Performance against these KPIs is shown in Table 4.They demonstrate the effectiveness of this Renewal and Maintenance strategy to mitigate the network related safety, reliability environment, financial, compliance and reputational risks in support of the achievement of the asset management targets and objectives are the number of Key Hazardous Events. These measures have been maintained at a low level historically, indicating the Renewal and Maintenance strategies have been effective at mitigating the risks and achieving the asset management objectives.

Table 4 – Network Asset Strategy KPI's – Underground Cables (Prescribed)

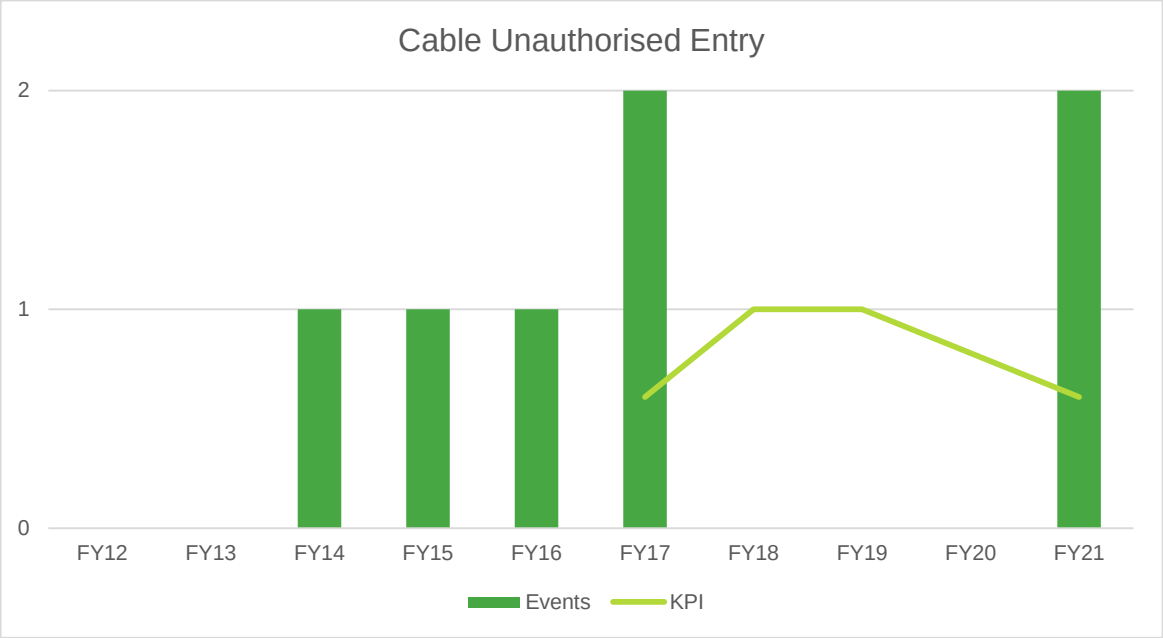
Asset Management Objective	Asset Management Performance Indicators	Past Performance
Manage network Safety Risk	• Maintain 5 yr. average of key hazardous (loss of control) events: - Catastrophic Failure - Unauthorised entry	• There were two unauthorised entry event recorded in CAMMS in 2021FY for underground cable assets. This caused the KPI to not be met. • No catastrophic failures occurred.
Manage network Safety Risk	No red reports in key result indicators regarding Bushfire, Reliability and Public Safety Principal Risk Dashboards	• Achieved. • BARC Reporting • Nil red results
Maintain network reliability	Maintain 5 year average level of loss of supply events due to line faults	Achieved. There were no loss of supply events from underground cable assets.
Maintain network reliability	Better than average performance of the STPIS measures: Achieve CY2021 STPIS result of $7.0m Achieve CY2021 STPIS result of $8.3m	• CY2020 STPIS was met. • CY2021 STPIS Performance is forecasting on track to meet target.
Manage assets efficiently without compromising security holder or customer value	Gain efficiencies in OPEX expenditure	• FY21 AMPOW annual budget achieved through prioritisation of work. • For asset class refer to section 3.1.3
Manage assets efficiently without compromising security holder or customer value	Achieve efficiency on regulated capital spend FY2021	Targeted capital efficiency was achieved in FY2021 and reinvested into the business

3.1.4.1. Past Performance – Unauthorised Entry

'Unauthorised Entry' was a new KPI introduced in the Network Asset Strategy and included in the FY2019 Renewal and Maintenance Strategy and has remained in the FY2022 update to the Network Asset Strategy. Transgrid have been report these incidents as part of the annual IPART ENSMS reporting and in the Public Safety Formal Safety Assessment (FSA). There were two instances in FY2021 so the KPI was

not met. None of these incidents resulted in asset damage although one did require significant investigations and costs are being pursued from the instigator.

Figure 6 – Unauthorised Entry



3.1.5. STPIS Performance

STPIS performance in CY20 was lower than previous years but aligned with strategic targets. This was due to many outages associated with upgrading numerous lines and substations associated with QNI. This was an expected result due to the large amount of critical work which needed to be completed.

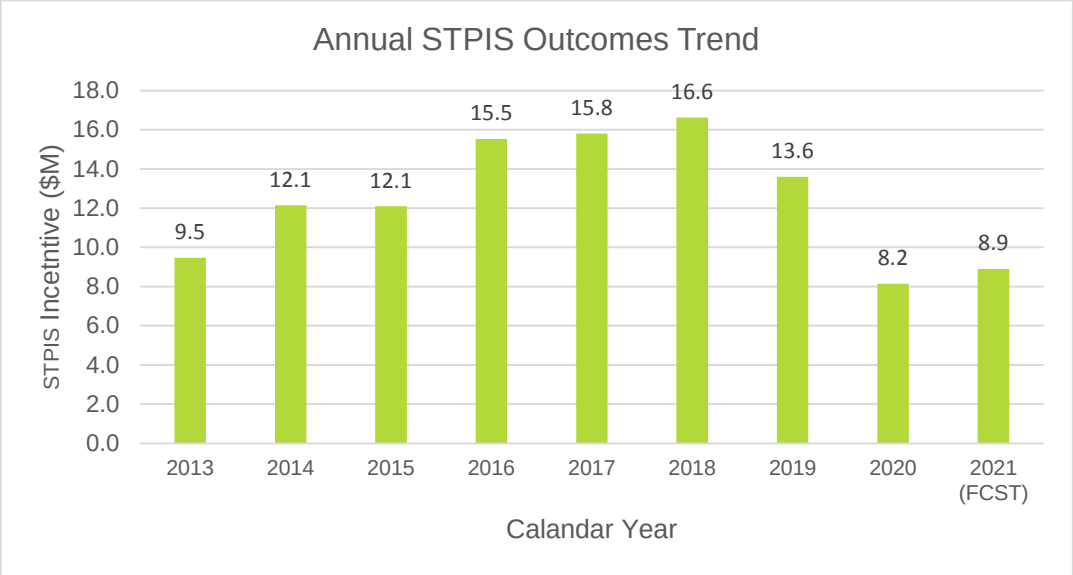
The effectiveness of our Asset Management program has contributed to STPIS performance by:

- Strategically targeted asset replacement programs for defective components of substation equipment, transmission lines, and digital infrastructure to improve asset reliability.

- Improved monitoring of assets and incident response by Asset Monitoring Centre and coordination with network planning for outage management.

- Maximising value achieved from Capital and Operating investment in our assets and minimising outages incurred

Figure 7 – Annual STPIS Outcomes Trend



3.1.5.1. Energy Not Supplied Events

There were five energy not supplied in FY2021. None were due to the underground cable asset fleet. The KPI for FY2021 was met.

3.2. Review of Strategic Initiatives

The status of relevant strategic initiatives from the Network Asset Strategy and other asset class specific strategic initiatives is provided in Table 5.

Table 5 - Strategic Initiative Status

Network Asset Strategy Objectives	Initiatives / Reference	Status
Deliver Safe Reliable Power		
Manage Network Safety Risk	Refer to Section 5	
Maintain network Reliability		
Create an efficient high performing business		
Ensure asset information is available to inform business-wide decisions	Continued collection of detailed asset condition data in AIM. Ready access to this data and integrating into the AAIT should empower the Asset Manager to make informed decisions.	Cable assets have not yet been set-up in AIM The Enterprise Asset Management project was avail an inspection system.
Manage assets efficiently to deliver security holder and consumer value.	Control Assurance Reviews (CAR's) to identify weakness and non-conformances in cable asset management practices.	One CAR was conducted in FY2021 on cable assets, focusing on route patrols.

Network Asset Strategy Objectives	Initiatives / Reference	Status
Grow Our Infrastructure and Services Business		
Support growth of non-regulated income as service provider of choice to the non-regulated market	Provide trusted advice to third party projects, such as Sydney Metro impacting on existing cables and for new non-regulated cable projects.	Ongoing. Positive feedback from external stakeholders.
Support new innovations and technologies		
Leverage AM to support new technologies that improve or grow our business	Use of Distributed Acoustic Sensing (Fiber Sense) to improve public safety and asset security.	The service is active on Cable 42. Fiber Sense have provided a proposal for installation on Cable 43/44 and 39 with provision for expansion to cover Powering Sydney's Future. It is now planned to deliver this in FY22 as part of Powering Sydney's Future.

4. Strategy

4.1. Strategy and Objectives

All strategic initiatives with respect to Transgrid's Underground Cable assets are outlined in this section, including the renewal and maintenance initiatives that contribute to the asset management program of works. Further details can be found in the relevant Maintenance Plans, and the referenced governance documents. The applicable Underground Cables objectives is shown in Table 6.

Table 6 – Asset management objectives and performance indicators – Underground Cables

Business Objective	Network Asset Strategy Objective	Asset Management Performance Indicators
Deliver safe reliable and low cost power	Manage network safety risk	• Maintain Network Safety LTIs and Fire Starts at Zero. • 5 year average level of Key Hazardous Events: - Catastrophic Failure - Unauthorised entry • No red reports in key result indicators regarding Bushfire, Reliability and Public Safety Principal Risk Dashboards
Deliver safe reliable and low cost power	Manage Network Safety Risk	Maintain 5 year level of environmental incidents
Deliver safe reliable and low cost power	Maintain network reliability	Maintain 5 year average level of loss of supply events
Deliver safe reliable and low cost power	Maintain network reliability	Target improvements to performance of the STPIS measures
Create and efficient, high performing business	Manage assets efficiently without compromising security holder and customer value	• Achieve +/- 5% performance in Program of Works Budgets. • Delivery Capital Program within +/-5%. • Target capital efficiency improvements.

To implement the strategic renewal and maintenance initiatives stemming from this document, actions are to be established via the:

- Maintenance Plan – Underground Cables: The maintenance plan outlines the routine maintenance tasks and frequencies for each asset type.
- Capital Works Program – The capital works program outlines the approved asset renewal and disposal projects.

The Transmission Line and Cables Asset Manager is responsible for preparation of the maintenance plan and referring the renewal and disposal initiative to the network investment process. Works Delivery is responsible for delivering the maintenance plans and Project Services are responsible for delivering the renewal and disposal initiatives detailed in the approved capital works program.

5. Renewal and Maintenance Initiatives

5.1. Underground Cable Asset Review

5.1.1. Population Review

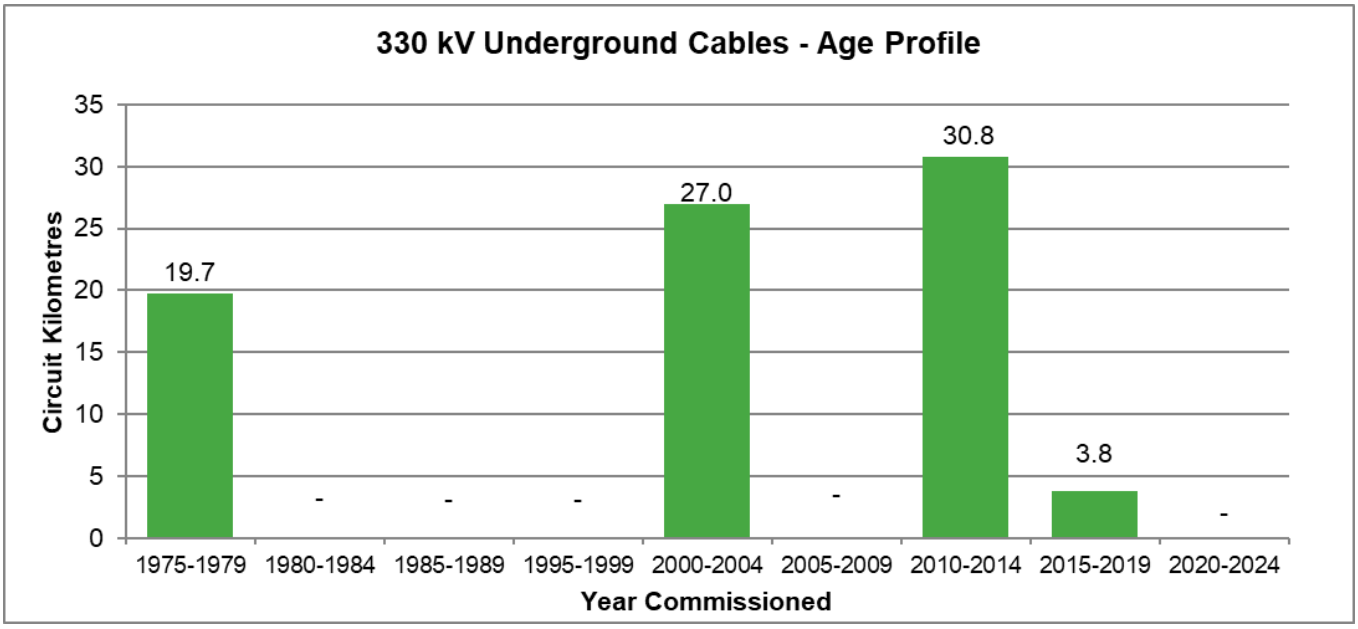
A good indication of asset health and obsolescence at a total population level can generally be provided by the age profile of the asset population – where assets have increased probability of deteriorating in health or becoming obsolete as they advance in age, and particularly as they approach the end of their nominal lifespan.

It is noted that TransGrid's underground cable assets are supported by associated systems, which typically have varying nominal lifespans shorter than the cables themselves. The associated Cable Monitoring Systems (CMS) typically have a limited lifetime due to computer components and operating systems becoming unsupported and some components may require renewal from 5 years after commissioning. Both the monitoring PC's and the site local controllers for the Cable 42 CMS were renewed in 2017.

5.1.1.1. 330 kV Underground Cable Age Profile

The 330 kV asset age profile is shown in below, it is made of the following circuit lengths:

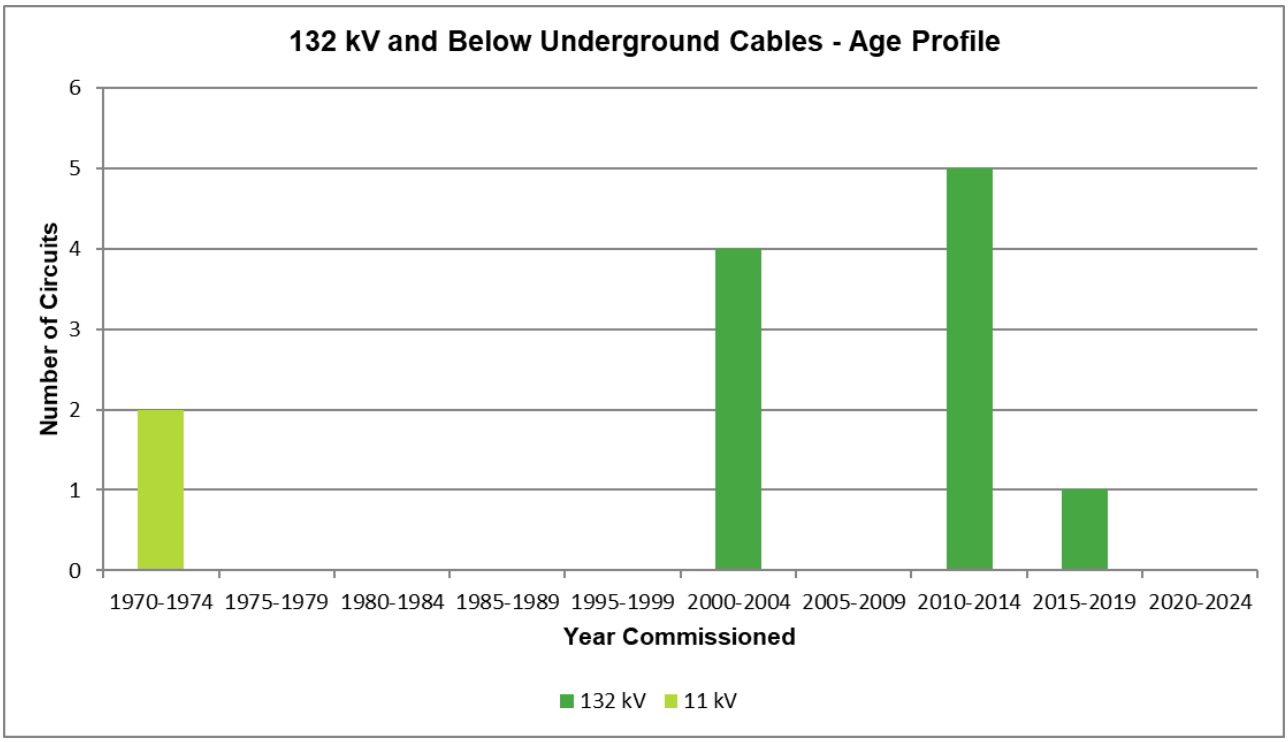
Figure 8 – 330 kV Underground Cable Age Profile



5.1.1.2. 132 kV and Below Underground Cable Age Profile

The 132 kV asset age profile is shown in Figure 9.

Figure 9 – 132 kV Underground Cables – Age Profile



Notwithstanding any intervening actions, this will result in the following outcome by June 2024:

All underground cables except for Cable 4 will remain within the first 50% of their nominal lifespan. Cable 41 has exceeded its 40 year design life.

These age profiles indicate that:

- Cable 41 which was installed in 1979 is the only cable likely to have issues with the cable itself and basic infrastructure. However due to the internally wiped joint design on Cable 41, the chance of oil leaks are much less likely than 132 kV cables of similar age with externally wiped joints.
- The cables installed from 2000-04 are unlikely to have issues with the cables and basic infrastructure. Defects and obsolescence associated with the Cable 42 CMS will unlikely have any issues as it was renewed in 2017. During the following regulatory period (2023/24-2028/29) some CMS components may be again approaching end of life.
- The cables installed from 2010-14 are unlikely to have any current or emerging issues. The Cable 43/44 CMS monitors temperature only, so is not as critical as the unit on Cable 42 which also monitors the oil system. Issues with the Cable 43/44 CMS are possible up to 2023 as the server components reach end of life, but given the nature of the system a run to fail approach is acceptable.

5.2. Cable 41 Asset Review

Cable 41 runs from Sydney South Substation to Beaconsfield Substation. It is an oil-filled cable and operates at 330 kV and was commissioned in 1979 with a nominal lifespan of 40 years. The cable is now approximately 40 years old and will have exceeded its nominal lifespan by 2024.

5.2.1. Emerging Issues and Renewal and Maintenance Initiatives

Table 7 maps out the line of sight of the Cable 41 emerging issues and renewal, maintenance and disposal initiatives to the Asset Management Objectives.

5.2.1.1. Cable 41 Emerging Issues

Cable 41 and Civil Works

Current and emerging issues concerning Cable 41 are summarised as follows:

- Overheating: The maximum electrical power transfer capacity, or 'rating', of a cable is fixed by its thermal operating limit. If the cable is operating at temperatures above its thermal limit this will accelerate the deterioration of its electrically insulating sheath. As the electrical insulation deteriorates the cable's probability of failure increases. Contributing factors:
    - The bedding in which a cable is buried plays a critical role in dissipating heat from the cable. The heat dissipating properties of the thermal bedding are factored into the circuit design and are a critical variable used to determine the cable rating.
    - In 2005 contractors excavating close to Cable 41 caused ground subsidence under the circuit. Following work to repair the damage it was found that the cement proportion in the thermal bedding (originally a 14:1 sand/cement mixture) was significantly reduced. Investigations at other locations found this to be consistent over the whole cable route.
    - Further analysis indicated that the cable may be operating above its thermal limit under certain circumstances as a result of the degradation of the thermal bedding. Essentially the analysis found that the heat dissipation is significantly lower than the cable's design specifications.
    - Further compounding the issue of poor heat dissipation is the suspected ambient ground temperatures along the cable route being higher than was assumed when determining the cable rating. This is indicated by the Cable Monitoring System (CMS) which operates with Cable 42; Cable 42 follows a similar route to Cable 41 and the Cable 42 CMS shows higher ground temperatures than the Cable 41 design specifications.
    - A recent initiative has installed temperature monitoring on Cable 41 to provide information on the operating conditions of the cable at six discrete points. The system also will allow system operators to react dynamically to prevent damage to the cable as temperatures vary.
    - In 2016 a comprehensive program of backfill sampling was conducted along Cable 41. Using the TR vs moisture and applying a minimum credible moisture contents the cable was subsequently derated to 426 MVA summer cyclic.
    - The 'Powering Sydney's Future' project is currently in delivery to replace the functionality of Cable 41 with a new 330kV cable (Cable 46). This project will utilise Cable 41 at 132 kV, an equivalent thermal rating will be given for operation at the new voltage.
- Core movement: Core movement at cable joints is a common failure mode for underground cables. In 1992 Cable 41 suffered an electrical fault at a cable joint which was attributed to core movement.
    - In 2011 core movement was detected on two further 'straight through' joints. The core movement was confirmed by x-ray and the joints were replaced with 'stop' joints to prevent further movement. The core movement was only detected due to the installation of core movement sensors and oil-line sampling installations following the 1992 failure. The remaining straight through joints on the cable are not equipped with movement sensors or oil sampling capability.

- It is likely that core movement is also occurring on the remaining joints which are not equipped with sensors and oil sampling capability.

- Joint issues – The Cable 41 ‘cut and sample’ project identified key issues within the joints. Carbonising was seen under the copper wires in the stress cone with significant paper penetration. Carbonising was found under the semistop penetrating actual cable insulation. These issues are load independent (voltage related) and exacerbated by switching or lightning surges superimposed onto the service voltage. The expert opinion is that given these issues the joints have a remaining life of approximately 8 years (from 2016). Damage to the o-ring gaskets found on both sides of the stop joint indicate that these joints are unable to be refurbished as there is no way of installing replacement gaskets without cutting the cable, necessitating the need for an additional joint.
- Sheath fault in JB5/6 – A sheath fault was detected in JB 5/6 in the centre of red phase joint. Investigations found a large void inside the joint coffin, resulting in no bitumen in contact with the copper case for a substantial area. Water was also found within, the apparent cause of the copper casing shorting. Clear evidence on how water had penetrated could not be identified. It is possible the void has been present since installation, perhaps due to the pour of compound not being continuous. It is reassuring that it was not caused by oil leakage as originally thought. Future instances may leave fault unrepaired as in this situation there was negligible change in sheath currents.

Cable 41 Tunnels

Current and emerging issues have been identified concerning two cable tunnels. These tunnels have access restrictions imposed on them due to concerns surrounding stability and water ingress. Inspections are conducted by a tunnel engineer every four years and prior to any major works. Any replacement works in the tunnel should occur within 3 months of one of the planned inspections.

These inspections have identified small areas of the crown requiring supporting works within the next 10 years. There refurbishments are planned for FY2022.

Cable 41 (26F) Spares

Sumitomo have provided notice to Transgrid that they will cease to manufacture SCFF cable and accessories from CY2025. Should all spares be depleted, no further repairs would be possible. In order to cover for a thermal runaway event, six spare joints are held for Cable 41. These holdings would be sufficient for three cable strike events. With Cable 41 at end of life and soon to be less critical, should events result in all spares be depleted, the cable will be retired.

5.2.1.2. Cable 41 Renewal Initiatives

Cable 41 is almost at the end of its scheduled life. The strategic renewal initiatives do not change the age profile. A backfill replacement (above the slabs only) was considered as part of several options with the proposed Powering Sydney’s Future (PSF) project but was determined as not being a credible option.

As part of the PSF project it is proposed to operate Cable 41 at 132 kV, which reduces the voltage stress issue causing issues at the joints. This will significantly decrease the consequence of failure with regard to reliability costs.

The oil pressure monitoring system installed on Cable 41 relies on the Telstra 3G network. Telstra propose to decommission this network in 2024. Renewal or modification to the system will be required to manage the oil pressure early warning alarms.

5.2.1.3. Cable 41 Maintenance Initiatives

Current maintenance initiatives on Cable 41 are as follows:

Cable 41 Tunnels - Works to support fretting of tunnel walls/ crown as advised by tunnel engineer. This work is planned for delivery as a renewal initiative in the 2018-2023 regulatory period. As part of routine maintenance the tunnel is being inspected to monitor the tunnels for signs of further deterioration.

Proactive measures to protect cables in public areas from external interference, such as security patrols.

Core movement is monitored on a small number of joint bay locations which has previously seen movement by the use of Hall Effect sensors and/or Dissolved Gas Analysis. It is hypothesised that the movement is caused by wave riding caused by heavy vehicle traffic. Core movement may be present at other locations and is a major risk for Cable 41. The installation of Hall Effect sensors and oil lines to allow oil sampling is very costly. The use of other methods, such as vibration monitoring using communications optical fibre, as a possible way to determine if wave riding is at a particular location is being considered by the Asset Manager.

With the reduction of criticality of Cable 41 when operating at 132 kV, the need for proactive monitoring is expected to decrease.

A Failure Mode Analysis was completed for the underground cables. The analysis is compared with the Underground Cables Maintenance Plan to demonstrate alignment between potential component failures and preventative maintenance activities prescribed to diagnose them. This is shown in Appendix A.

5.2.1.4. Cable 41 Disposal Initiatives

The Cable 41 temperature monitoring system will become ineffective in 2024 when Telstra decommissions the 3G network. The current system is limited in effectiveness as it is only a spot monitoring system and may not necessarily be covering the hottest location. These locations also have unmetered power supplies which have much higher assumed usage than the monitoring systems consumes. Decommissioning the system will eliminate these electricity charges.

Table 7 – Cable 41 - Emerging Issues, and Renewal and Maintenance Initiatives

Assets	Asset Management Objective	Emerging Issues	Strategic Initiative	Progress (completion and expenditure)	Reference Documents
Cable 41	• Maintain network reliability	• Stability concerns and water ingress affecting the Cable 41 tunnels	• Works to support fretting of tunnel walls/ crown as advised by tunnel engineer. • Monitor through routine inspections with tunnel specialist	RP2 Est $240,000	Need ID: 1088 Maintenance Plan – Underground Cable Assets
Cable 41	• Maintain network reliability	• Potential cable joint core movement on Cable 41	• Monitor for core movement via DGA and core movement sensors as part of routine maintenance. • Run to failure (no monitoring) once Cable 41 is operational at 132 kV.	Ongoing	Maintenance Plan – Underground Cable Assets
Cable 41 on-line pressure monitoring	• Maintain network reliability • Manage assets efficiently to deliver security holder and consumer value	• System will reach end of life in RP3. • System relies on the pilot cable for power source. The pilot cable is at end of life.	• Replace existing system.	Included in RP3 submission.	N2490
Cable 41 (26F) temperature monitoring	• Manage assets efficiently to deliver security holder and consumer value	• System at end of life. • 3G network will be decommissioned.	• Decommission system.	Included in RP3 submission.	N2490

Assets	Asset Management Objective	Emerging Issues	Strategic Initiative	Progress (completion and expenditure)	Reference Documents
All cable assets	• Ensure asset information is available to inform business-wide decisions	• Not all maintenance checksheets are loaded into Ellipse or AIM.	• Move cable maintenance into AIM.	AIM stg 2 will not go ahead.	Need ID:1068 (IT Project)
HV Cables outside substations	• Manage Network Safety Risk	• Members of the public digging in the vicinity of TransGrid HV cables	• Monitor via daily patrols of Cable 41. • Proactive approach in communication with contractors via DBYD. • Near misses and unauthorised excavations reported in AIM and CAMMS as appropriate. • Provide TransGrid 'standby' to contractor during works that potentially impact on the cable installation. • Consider the use of vibration monitoring using optical fibre.	• Ongoing - $160k FY22 budget for daily patrol • Vibration monitoring will not proceed, as it is not economically justified.	Maintenance Plan – Underground Cable Assets

5.2.2. Maintenance Program

Routine patrols mitigate and address the possibility of damage to the cable by external parties. The greatest routine inspection/maintenance cost on this cable is the route patrols, which are conducted six days a week. In 2021FY the work order costs of Cable 41 route patrols was $190K.

Repair times are long, very costly and very disruptive to the public. These patrols have been effective in preventing damage on a number of occasions and as such there will be no changes to the frequency of this item.

There are synergies of Cables 41 and 42 inspections. Cable 41 would be patrolled one way and the return trip would be completed on Cable 42. When Distributed Acoustic Sensing was installed on Cable 42 the net patrol costs were mostly unchanged (when including DAS service). After Powering Sydney's Future, when Cable 41 becoming less critical when operating at 132 kV, patrols can be reduced, allowing sufficient savings.

In addition to the daily patrols, TransGrid provides a 'standby' to monitor safety aspects during works by an External Party in the vicinity of a TransGrid underground Cable. These have been currently provided at nil cost to the contractor (with the exception of major ongoing works such as Sydney Metro and Westconnex). Options on being able to charge external parties for these standby works are being considered.

5.3. Cable 42 Asset Review

Cable 42 runs from Sydney South Substation to Haymarket Substation. It is an oil-filled cable and operates at 330 kV and was commissioned in 2004 with a nominal lifespan of 40 years.

5.3.1.1. Cable 42 Emerging Issues

In early CY2021, Sumitomo advised Transgrid that they intend to discontinue manufacture of SCFF cable and accessories. Cable will be discontinued 2025 (order deadline 2023); accessories 2028 (order deadline 2023). Existing spares can only cover for one strike or failure. As Cable 42 is only halfway through its nominal life additional spares will be required to ensure ongoing response capability.

The Cable 42 CMS was replaced in April 2017 but not installed according to the need. Individual wired alarms only go through to the local HMI; they are not making it through to SCADA. This was not remediated as part of prior to close out. Investigations completed under defect maintenance determined that the system was operating "as per design". This was clearly not as per need statement and project brief. Getting this rectified will require further design resources under IWR.

The MetroGrid tunnel 'leaky feeder' cable is used for monitoring and control signalling between the Ground Water Treatment Plant and the sump. The tunnel environmental monitors are also connected to this cable as part of the Cable Tunnel Monitoring System. The media converters are faulty and the telemetry modules frequently drop out. This can result in nuance erroneous alarms and has even at time resulted in causing the sump pumps to not operate. This issue will be managed under Digital Infrastructure asset class and has been an ongoing issue for over 12 months.

5.3.1.2. Cable 42 Renewal Initiatives

Twelve (12) Cable 42 spares joints are proposed for capital spares purchase during RP3 to enable repairs for at least the forecast end of life of the asset.

The Cable 42 CMS, which has a nominal life of ten years will reach end of life during RP3.

5.3.1.3. Cable 42 Maintenance Initiatives

There are no current maintenance initiatives on Cable 42.

The leaky feeder issues are being addressed as part of Digital Infrastructure's maintenance initiatives.

A Failure Mode Analysis was completed for the underground cables. The analysis is compared with the Underground Cables Maintenance Plan to demonstrate alignment between potential component failures and preventative maintenance activities prescribed to diagnose them. This is shown in Appendix A.

5.3.1.4. Cable 42 Disposal Initiatives

There are no current Cable 42 disposal initiatives.

Table 8 – Cable 42 - Emerging Issues, and Renewal and Maintenance Initiatives

Assets	Asset Management Objective	Emerging Issues	Strategic Initiative	Progress (completion and expenditure)	Reference Documents
Cable 42	• Maintain network reliability	• Manufacturer support for supply of SCFF cable and accessories is being withdrawn from 2025 to 2028.	• New SCFF to XLPE joints to allow repairs of Cable 42 using the XLPE cable spares for Cable43/44. • Renew XLPE spares at end of shelf life.	RP3 Est $2.75 million (includes XLPE spares)	Need ID: N2488
Cable 42	• Maintain network reliability	• Cable condition monitoring system will reach end of life approx. 2027.	• Renew monitoring	Included in RP3 submission.	Need ID: N2490

5.4. Cable 43/44 and 39 Asset Review

Cable 43/44 runs from Holroyd and Rookwood Road Substation. Cable 39 is installed in the middle of Transmission line 39. It runs along the perimeter of the Western Sydney airport site, two transition sites convert the circuit from overhead to underground arrangement. These are both 330 kV XLPE cable systems.

5.4.1.1. Cable 43/44 and 39 Emerging Issues

XLPE joints and terminations, when stored as spares have limited shelf life. Generic items such as oils and tape can be purchased on an 'as needed' basis. Items such as stress cones are specific to the cable system and have long lead times. For Cable 43/44 these items have a shelf life of ten years.

5.4.1.2. Cable 43/44 and 39 Renewal Initiatives

The Cable 43/44 spares will either need to be renewed or a service agreement initiated with the manufacturer for supply of accessories when required on short lead time. The preferred option included in the RP3 submission was for spares renewal.

The Distributed Temperature Monitoring System on Cable 43/44 will reach end of life during RP3. Its replacement has been included in the submission.

5.4.1.3. Cable 43/44 and 39 Maintenance Initiatives

In July 2020, a scar was encountered on the road in Parkes St, Guildford West as a result from a road crossing that was not reviewed by TransGrid. Subsequent testing of the ECC has indicated no issues, however that does not completely rule out damage, which required the site to be excavated. Damage is possible due to the design of the cable in this location, based on the information provided by the offending party. Investigations found no damage. Transgrid is attempting to recover costs for the investigations.

If acoustic monitoring had been in place on this circuit the incident may have been prevented. Fiber Sense have submitted a proposal to monitor Cable 43/44 and 39 from a single unit located at Holroyd. After this installation it will be a simple process to extend to Powering Sydney's Future.

A Failure Mode Analysis was completed for the underground cables. The analysis is compared with the Underground Cables Maintenance Plan to demonstrate alignment between potential component failures and preventative maintenance activities prescribed to diagnose them. This is shown in Appendix A.

5.4.1.4. Cable 43/44 and 39 Disposal Initiatives

There are no current disposal initiatives.

Table 9 – Cable 43/44 and 39 - Emerging Issues, and Renewal and Maintenance Initiatives

Assets	Asset Management Objective	Emerging Issues	Strategic Initiative	Progress (completion and expenditure)	Reference Documents
Cable 43/44	• Maintain network reliability	• Shelf life of Cable 43/44 will be exceeded in 2024.	• Renew spares during RP3	Included in RP3 submission.	N2490
Cable 43/44 and 39	• Manage Network Safety Risk	• Members of the public digging in the vicinity of TransGrid HV cables	• Monitor via patrols. • Proactive approach in communication with contractors via DBYD. • Near misses and unauthorised excavations reported in AIM and CAMMS as appropriate. • Provide TransGrid 'standby' to contractor during works that potentially impact on the cable installation. • Consider the use of vibration monitoring using optical fibre.	Ongoing	Maintenance Plan – Underground Cable Assets

5.5. 132 kV cables and below Asset Review

TransGrid has short lengths of 132 kV underground cables in Haymarket, Beaconsfield and Rookwood Road substations. All cables are XLPE construction, commissioned 2003 at the earliest.

TransGrid also owns the 11 kV supply cables from Essential Energy's Talbingo 66 kV Zone Substation to Lower Tumut Switching Station.

5.5.1.1. 132 kV Cables and Below Emerging Issues

The 132 kV cables are all XPLE construction, commissioned in 2004 at the earliest.

The Haymarket tie cables have low sheath IR's due to the fire stopping arrangements installed around the cable.

The one cable termination to No.2 Capacitor at Beaconsfield was destroyed when the wall of the adjacent property collapsed during a fire (April 2018).

The 11 kV Lower Tumut supply cables utilised steel potheads. Essential Energy informed TransGrid that these items are a safety and fire risk, which they have been replacing as part of a strategy.

5.5.1.2. 132 kV Cables and Renewal Initiatives

For the 11 kV potheads on the Lower Tumut supply cables, TransGrid has engaged Essential Energy to complete these replacements.

The Beaconsfield No.2 Capacitor Cable termination will be repaired as part of the restoration project (recoverable works).

5.5.1.3. 132 kV Cables and Below Maintenance Initiatives

In order to determine the integrity of the 132 kV cable bonding system in Haymarket additional testing of the SVL's are required 'tong test'. This is conducted as part of routine inspections.

All 11 kV potheads at Talbingo have been replaced, reducing fire risk and ensuring reliability of auxiliary supplies to Lower Tumut Switching Station.

5.5.1.4. 132 kV Cables and Below Disposal Initiatives

There are no current disposal initiatives.

Table 10 – 132 kV and Below Cables – Emerging Issues, and Renewal, Maintenance and Disposal Initiatives

Assets	Asset Management Objective	Emerging Issues	Strategic Initiative	Progress (completion and expenditure)	Reference Documents
Haymarket 132 kV Cables	• Manage assets efficiently without compromising security holder and customer value	• Fire stopping between basement levels can cause lower sheath insulation readings.	• As part of routine inspections, confirm bonding functionality by measuring sheath currents.	Ongoing	Underground Cables Maintenance Plan
Lower Tumut 11 kV supply Cables	• Manage Network Safety Risk • Maintain network reliability	• Cast iron potheads can fail catastrophically. This is a safety and a fire start risk.	• Replace both cast iron potheads with new termination.	All potheads have been replaced.	Defect Work Order Essential Energy AER revenue proposal. Essential Energy Asset Management Distribution Annual Planning Reports
Beaconsfield No.2 Capacitor Cable	• Manage assets efficiently without compromising security holder and customer value	• Cable termination destroyed by neighbouring building collapse in April 2018.	• Make capacitor bank serviceable, including repairs or replacements to cable terminations	$1.26 M budget IWR need date Dec 2020, forecast completion March 2021. Cost recovery will be attempted.	IWR0196

6. CAPEX Forecasts

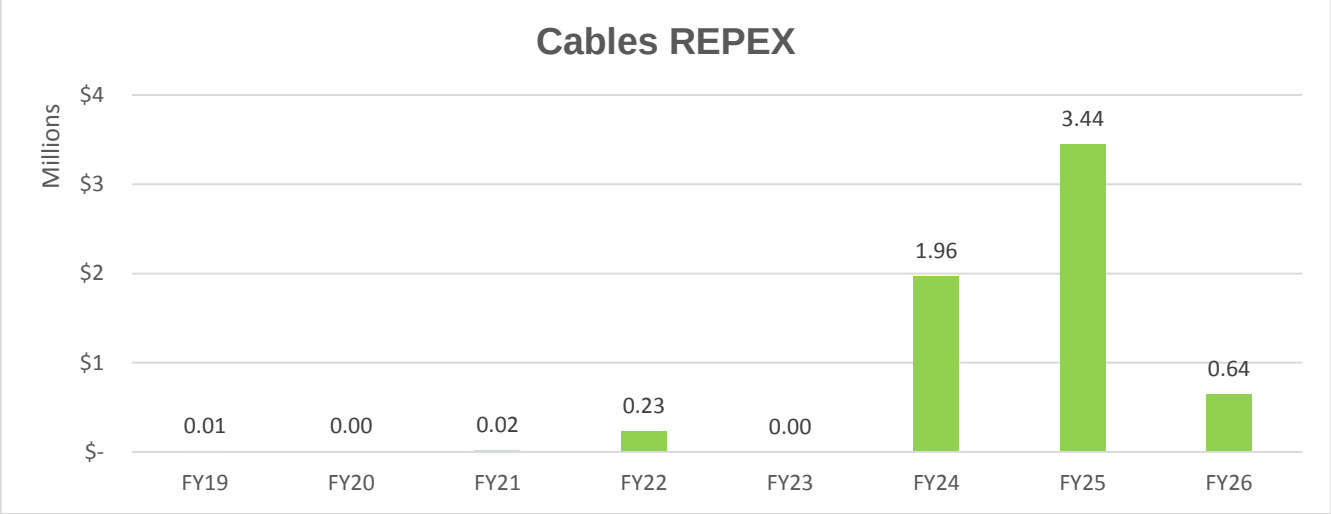
6.1.1. 5 year CAPEX Profile

The significant upcoming underground cable CAPEX works is Powering Sydney's Future.

The five year CAPEX forecast for underground cables REPEX is $6.05 million. The powering Sydney's Future augmentation project has not been included. Apart from a small remediation project on the Cable 41 trunnels, there are no other CAPEX projects planned in RP2. For RP3, capital spares and monitoring system renewal are proposed.

The five-year breakdown is shown in Figure 10

Figure 10 – Cables Forecast REPEX



6.1.2. Anticipated Changes to the Asset Base

The following changes to the prescribed Underground Cable Asset Base are anticipated:

- Powering Sydney's Future (Augex) – Delivery 2022FY

The delivery of Powering Sydney's Future will reduce the criticality of Cable 41, reducing TransGrid reliability risks. Cable 41 will remain operational at 132 kV, under the number 26F. These projects will result in the average age of the underground cable asset base to decrease.

6.1.3. Long Term - REPEX Investment Framework

Transmission cables are not included in the Repex forecasting model. The following unique attributes of transmission cables result in them being unsuited to age based Repex forecasting:

A significant proportion of the costs associated with replacing an aged segment of cable is the specialist labour costs required to join the new cable segment to the old. To illustrate with an example, 640m of damaged (due to an excavation incident) Cable 43 was replaced in 2014 at a cost of $5M. The material cost of the cable itself was only $400k by comparison. So for example, the cost to replace a single 2 km segment of aged cable is considerably less than replacing two separate aged 1km segments. Contrast with

transmission lines where the replacement costs (both labour and materials) are more or less in proportion to the length being replaced. As a result, length based Repex forecasting for cables is unsuitable.

If instead of length based Repex forecasting, entire cable Repex forecasting is assumed, the small sample size of transmission cables in our network (five cables in total) would result in wildly inaccurate Repex forecast trends.

TransGrid's transmission cables are all located in the Sydney metropolitan area and are in parallel with Ausgrid's heavily meshed sub-transmission network in the region. As a result, the drivers for replacing these cable assets are based on many other variables aside from asset age, to a greater extent than other asset types. A transmission cable can be de-rated (i.e. operate at a lower capacity) by installing a series reactor to reduce the flows on the cable at a significantly lower cost than replacing the cable, and doing so can extend the life of the cable beyond the nominal life which could be more economical than replacement (as has been done with cable 41). The viability of extending cable life by de-rating in this manner is heavily dependent on developments in Ausgrid's parallel sub-transmission network, local demand trends, and the availability of non-network alternatives. In summary, a cable approaching end of life is less likely to trigger a like for like replacement, Augex options are likely to play a more significant role in addressing the risk of ageing cable assets, in comparison to other asset types.

7. OPEX Forecasts

OPEX forecasts provided by Asset Analytics and Insights exclude the impact of augmentation projects. All costs are in future year dollars.

7.1.1. Discussion of significant changes to Maintenance Plan

Powering Sydney's Future is expected to be commissioned around December 2021. The six-day a week patrols on Cable 41 will no longer be required. This is expected to result on an overall decrease in inspection costs, provided Fiber Sense is operational on Cable 42 and Powering Sydney's Future. Maintenance activities on the new Cable 46 will however commence.

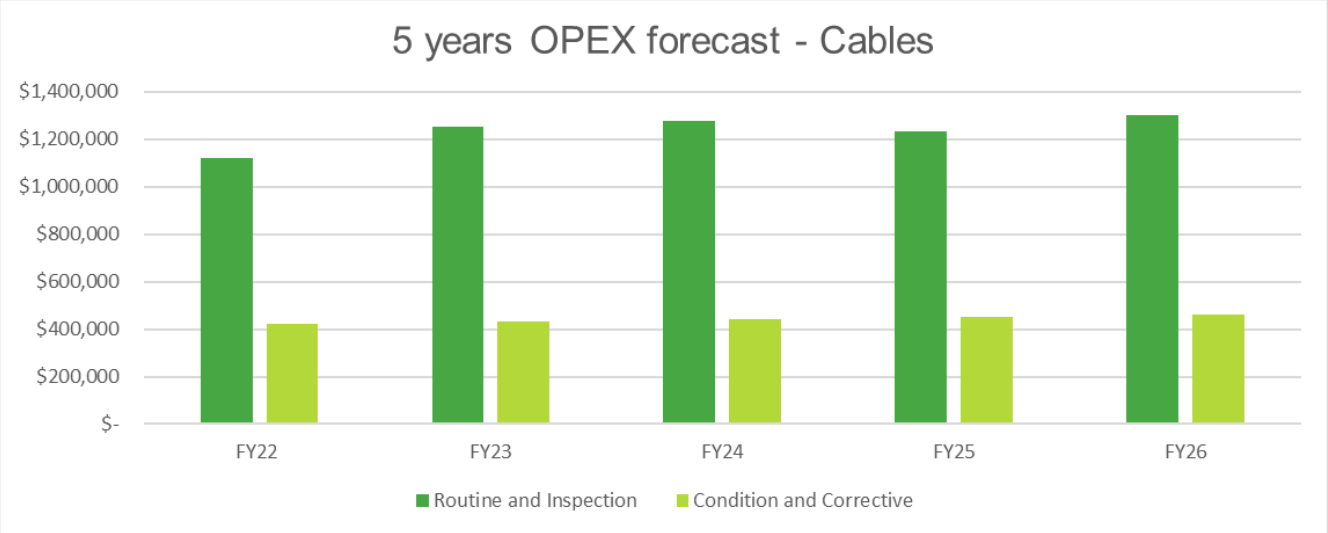
7.1.2. 5 year OPEX Profile

The five-year OPEX trends for Underground Cables is shown in Figure 11.

The following shall be noted:

- Support cost have been included.
- Volume of Corrective and Condition is maintained at the same level
- Escalation is as per CPI forecast provided by Transgrid Finance.
- Stretch target has not been included.

Figure 11 – Five-Year Underground Cable OPEX Forecast



8. Definitions

Term	Definition
Key Hazardous Events	They events of most concern associated with the assets that prevent the achievement of the corporate and asset management objectives.
Emerging Issues	Newly identified issues with an asset that pose a risk to the achievement of the corporate and asset management objectives.
Fault Outage	AER defined term - Fault outages are unplanned outages (without notice) on the prescribed network from all causes including emergency events and extreme events.
Forced Outage	AER defined term - Forced outages are outages on the prescribed network where less than 24 hours notification was given to affected customers and/or AEMO (except where AEMO reschedules the outage after notification has been provided). Forced outages exclude fault outages.
Asset Management Plans	Documents specifying activities, resources, responsibilities and timescales for implementing the asset management strategy and delivering the asset management objectives.
RP1	Regulatory Period 2014/15 – 2017/18
RP2	Regulatory Period 2018/19 – 2022/23
RP3	Regulatory Period 2023/24 – 2022/28
RP4	Regulatory Period 2028/29 – 2030/33

9. Document Management

9.1. Monitoring and review

Implementation of the Underground Cable Renewal and Maintenance Strategy is monitored and reviewed by the Transmission Lines and Cables Asset Manager, Head of Asset Management and Asset Management Committee annually.

9.2. Roles and Responsibilities to Develop this Asset Strategy

The roles and responsibilities of those responsible for the development of this asset strategy are as follows:

The Head of Asset Management is responsible for the approval of this strategy.

The Transmission Lines and Cables Asset Manager is responsible for the development and regular review of this strategy. The document will be reviewed annually and when significant changes to investment needs become apparent.

9.3. References

Network Asset Strategy

Asset Management Policy

Asset Management System Description

Underground Cables Maintenance Plan

Non-prescribed Asset Management Plan

Prescribed Capital Investment Process

Optimised Investment List (OIL)

Cable Assets Condition Monitoring Manual

Appendix A Failure Mode Analysis

Part	Sub-Part	Failure	Cause	Asset Type	Maintenance Plan Task
Cable		Damaged	Human Interference	All Cables	• Cable Patrols • Distributed Acoustic Sensing (Fiber Sense) • Provide cable spotter for work near TransGrid cables
		Damaged	Easement Encroachment	All Cables	• Cable Patrols • Distributed Acoustic Sensing (Fiber Sense)
	Backfill	Damaged	Human Interference	All Cables	• Cable Patrols • Distributed Acoustic Sensing (Fiber Sense) • Provide cable spotter for work near TransGrid cables
	Backfill	Loss of Moisture	Easement Encroachment	All Cables	• Cable Patrols • Easement & Access track inspections
	Backfill	Washout	Installation Error	Cable 41 and 42	• Cable Patrols • Easement & Access track inspections
	Backfill	Deteriorated	Acid Sulfate Soils	Cable 41 and 42	• Monitor cable temperatures of with Cable 42 CMS and Cable 41 point measurement systems.
Cable Sheath	Aluminium Sheath	Corroded	Outer Sheath Failure	All Cables	• Outer Sheath Test
Cable Sheath	Outer Sheath	Deteriorated	Normal wear and tear	All Cables	• Outer Sheath Test
Cable Sheath	Outer Sheath	Damaged	Human Interference	All Cables	• Cable Patrols • Distributed Acoustic Sensing (Fiber Sense) • Provide cable spotter for work near TransGrid cables • Outer sheath test
	Aluminium Sheath	Oil Leak	External interference	Cable 41 and 42	• Pressure readings and Alarm Checks • Cable 42 CMS Maintenance • Gauge Calibration

Part	Sub-Part	Failure	Cause	Asset Type	Maintenance Plan Task
Cable Oil line	Oil line connections	Oil Leak	Material	Cable 41 and 42)	• Pressure readings and Alarm Checks • Cable 42 CMS Maintenance • Outer Sheath • Gauge Calibration
Cable Joints		Core movement	Vibration	Cables 41, 42, 43/44	• Core movement measurements • Cable Fluid samples
		Deteriorated	Expected wear and tear	330 kV Cables	• Outer sheath test • Cable fluid samples
			Design – general	330 kV Cables	• Outer sheath test • Cable fluid samples
		Oil leak	• Design – General • Design – Material	Cable 41	• Outer sheath test
Link Box	Seals	Deteriorated	Expected wear and tear	330 kV Cables	• Outer Sheath test • Link box and oil pit maintenance
	Link box pit	Collapsed	Human Interference	330 kV Cables	• Cable Patrols • Distributed Acoustic Sensing (Fiber Sense) • Provide cable spotter for work near TransGrid cables
	Connections	Deteriorated	• Expected wear and tear • Design – Material	330 kV Cables	• Outer Sheath test
	Sheath Voltage Limiter	Damaged	Design – Material	All 330 kV and 132 KV Cables	• Outer Sheath test
Cable Terminations		Deteriorated	• Expected wear and tear • Design –	All cables	• Sealing end inspection (minor maintenance) • Sealing end major maintenance

Part	Sub-Part	Failure	Cause	Asset Type	Maintenance Plan Task
			General		
		Oil leakage	• Design – Material	Cable 41 and 42	• Sealing end inspection (minor maintenance)
	Insulator Sheds	Damaged	• Human Interference	Cable 41, 42 and 39	• Sealing end inspection (minor maintenance) • Cable route patrol • After fault patrol
Cable	Insulation	Deteriorated	• Expected wear and tear	All cables	• Nil
			• Design – General	All cables	• CMS operational inspection • CMS maintenance • DTS calibration check • CMS database back-ups • Monitor cables with Distributed Temperature Sensing • Bridge sunshade inspection • Fluid Sampling
			• Installation Error	All cables	• CMS operational inspection • CMS maintenance • DTS calibration check • CMS database back-ups • Monitor cables with Distributed Temperature Sensing • Fluid Sampling
			• Management Error	All cables	• Other services crossings TransGrid cables must be checked by Asset Management and Design
Oil sampling point	Piping	Deteriorated	• Expected wear and tear	Cable 41 and 42	• Pressure readings and Alarm Checks • Cable 42 CMS Maintenance
Oil sampling pit	Pit	Flooded	• Ingress of water	Cable 41 and 42	• Pressure readings and Alarm Checks
	Gatic keyhole	Worn	• Expected wear	Cable 41 and	• Pressure readings and Alarm Checks

Part	Sub-Part	Failure	Cause	Asset Type	Maintenance Plan Task
			and tear	42	
Oil Valves		Seized	• Expected wear and tear	Cable 42	• Emergency valve operation check
		Failed	• Software Fault • Hardware Fault	Cable 42	• Emergency valve operation check
Oil pressure monitoring	Gauge	Incorrect	• Calibration drift	Cable 41 and 42	• Pressure readings and Alarm Checks
	Transducer	Failed	• Electrical Fault	Cable 41 and 42	
		Incorrect	• Calibration Drift	Cable 41 and 42	
	Switch	Failed	• Expected wear and tear	Cable 41 and 42	
Oil Tank	Tank	Contaminated	• Corrosion	Cable 41 and 42	• Cable fluid sampling
	Seals	Leaking	• Expected wear and tear	Cable 41 and 42	• Pressure readings and Alarm Checks
Cable Monitoring System	Fibre optic cable	Damaged	• External Interference	Cable 42, 43/44 and 39	• Monitoring System Operational Check
	Local Controller	Failed	• Hardware fault	Cable 42	• Monitoring System Operational Check
	Monitoring system server	Failed	• Hardware fault • Software fault	Cable 42, 43/44 and 39	• Monitoring System Operational Check
Cable structure and bridge		Deteriorated	• Expected wear and tear	Cable 41 and 42	• Above ground structure inspection
Cable Marker		Deteriorated	• Expected wear and tear	All 330 kV cables	• Cable route patrol
		Missing	• Human interference		

Part	Sub-Part	Failure	Cause	Asset Type	Maintenance Plan Task
		Damaged	• Human interference		