ACS POWER CABLES

Fleet Strategy

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Keeping the energy flowing




TRANSPOWER

Table of Contents

TRANSPOWER

EXECUTIVE SUMMARY

Introduction

Most of our main transmission network relies upon overhead transmission lines. However, high-voltage (HV) power cables are becoming an increasingly important element of the system. Our HV cables provide transmission services in urban areas where the use of overhead lines is undesirable. Medium-voltage (MV) cables are used extensively for connections within substations.

Our asset management approach for power cables seeks to achieve least overall lifecycle cost and ensure appropriately high levels of reliability.

Asset fleet and condition assessment

We have recently added a substantial quantity of 220 kV and 110 kV power cables to the fleet as part of network enhancement and development projects. Following the commissioning of the North Island Grid Upgrade (NIGUP) and North Auckland and Northland (NAaN) projects there is now approximately 50 km of 220 kV cable circuits in the Auckland region. There is also approximately 8 km of 110 kV cable circuits.

As part of the installation of the new 220 kV cables in the Auckland region, we have installed Distributed Temperature Sensing (DTS) systems to provide more confidence about the thermal capability and rating of the cables.

In addition to the longer HV cable circuits, we have 47 cable circuits of less than 1 km in length operating at 220 kV and 110 kV, mostly within substation boundaries.

There are approximately 1,060 MV cable circuits, operating at voltages between 11 kV and 66 kV. These cable circuits are all of short length, generally less than 100m.

Power cables are usually highly reliable. For cables installed outside of controlled areas, the main risks arise from damage caused by third parties during excavations.

A general characteristic of power cables is that fault repairs take a long time to complete when compared with fault repairs of an overhead line. The security of the transmission service may be reduced for an extended period following a cable failure, because of the time required to undertake repairs.

The majority of our power cables use copper conductor with cross-linked polyethylene (XLPE) primary insulation. In general, this type of cable is in good condition, with a long life expectancy. However, we also have older technology 220 kV oil-filled cables in service. There are eight 220 kV oil-filled cable circuits, with an average age of 31, installed at Bream Bay, New Plymouth, Rangipo and Wilton substations. Oil-filled cable technology was superseded more than 20 years ago. There have been no major failures of these cable circuits, but there are indications of deteriorating condition. Spares holdings are limited, and there would be a long lead time for procuring special components for undertaking major repairs as the number of manufacturers is diminishing.

The configuration of the Bream Bay and Wilton sites means that in the event of a cable failure, it would not be possible to energise the associated 220/33 kV power transformer or to directly use the strategic spare power transformer because of incompatibility with the oil connection boxes. Therefore, a failure of one of the 220 kV oil-filled cable circuits would lead to a sustained period of reduced security.

Bream Bay substation is of particular concern because it supplies a nationally significant load at the New Zealand Oil Refinery at Marsden Point. Even small interruptions of supply have the potential to cause major disruption to the refinery, and significant losses. A loss of supply to the refinery could lead to fuel supplies becoming depleted in the Auckland region initially and may affect the rest of the country if sustained.

Defects have been found with the Bream Bay 220 kV oil-filled cables. Repairs have been made, but there are concerns about the future reliability of these cables and the potential consequences of cable failure.

The fleet of MV cables is generally very reliable, but we have had a number of failures of cable terminations that have been attributed to poor workmanship during installation.

Power cable strategies

For the newly installed 220 kV cables in the Auckland region, we will undertake regular patrols of the cable routes to mitigate the risk of damage caused during excavations by third parties. Initially these route patrols will be on a weekly basis, which represents a step change in our routine maintenance activities. A programme will also be established to undertake annual routine tests on each one of these critical HV cable circuits. We will gain more experience with the use of the newly installed DTS systems, to improve our operational capability, and plan for the upkeep of these systems.

The aged 220 kV oil-filled cables at Bream Bay, New Plymouth, Rangipo and Wilton substations require particular attention to mitigate risk. We will undertake a special programme of condition assessment on all these oil-filled cable circuits. The Bream Bay cables present the highest risk, and we propose that they be replaced during the RCP2 period. For the remaining 220 kV oil-filled cables, we plan to undertake a programme of refurbishment and repair.

To ensure future reliability of our fleet of MV cables, we will improve training and competency requirements for installing cable terminations, and undertake a trial of partial discharge (PD) mapping to identify cables at elevated risk of failure.

Improvements

In our planning for the RCP2 period we have made a number of improvements to the asset management of power cables.

- Our planning decisions consider the whole-of-life cost of power cable assets covering Planning, Delivery, Operations, Maintenance and Disposal, as well as their impacts on other assets, such as transformers, indoor switchgear and outdoor to indoor conversions.
- Asset criticality is being used as an important factor in planning power cable asset works – in particular replacements.
- Cost estimation for projects in RCP2 has been undertaken using tailored 'building blocks' based on actual cost out-turns from completed or equivalent works.

Further improvements will include:

- refinements to the power cable asset knowledge, including pilot investigations into PD mapping of our MV cable fleet
- refinement of the asset criticality framework.

SUMMARY OF STRATEGIES

This section provides a high-level summary of the main asset management strategies for the power cable fleet over the RCP2 period.

Main strategies

The following summaries include the main strategies and their respective costs during the RCP2 period (2015–2020).

Capital expenditure (capex)

HV cable replacement	RCP2 Cost	**$5.8m**
Our strategy is to replace the 30-year-old 220 kV oil-filled cables at Bream Bay substation. These cables are showing signs of deteriorating condition, and are a legacy technology that is becoming increasingly difficult to support. The Bream Bay 220 kV cables supply the New Zealand oil refinery at Marsden Point, and interruptions to this supply could have nationally significant economic consequences.		

DTS systems replacement	RCP2 Cost	**$1m**
Our strategy is to undertake lifecycle replacement of the four Distributed Temperature Sensing (DTS) systems provided as part of the major 220 kV cables installed recently in the Auckland region. These DTS systems are expected to reach the end of their useful lives prior to the commencement of the RCP3 period.		

New oil treatment equipment	RCP2 Cost	**$670k**
Our strategy is to procure a cable oil treatment unit to improve our ability to manage the oil quality in our 220 kV oil-filled cables, and respond promptly to any urgent repairs.		

Operational expenditure (opex)

HV oil filled power cable repairs	RCP2 Cost	**$1.5m**
Our strategy is to repair the 220 kV oil-filled cables at Wilton, New Plymouth and Rangipo substations to reduce the likelihood of major outages due to cable failures. The repair works will require specialist skills and equipment. We plan to undertake major repairs of oil-filled cable circuits at three sites at an estimated total cost of $1.5m over the RCP2 period.		

Chapter 4 has further details on these strategies and a discussion of the remaining strategies.

1 INTRODUCTION

Chapter 1 introduces the purpose, scope, stakeholders, and strategic alignment of the power cables fleet strategy.

1.1 Purpose

We plan, build, maintain and operate New Zealand's HV electricity transmission network ('Grid') which includes our fleet of underground power cables.

The purpose of this strategy document is to describe our approach to lifecycle management of the fleet of power cables. This includes a description of the asset fleet, objectives for future performance and strategies being adopted to achieve these objectives.

The strategy sets the high-level direction for fleet asset management activities across the lifecycle of the asset fleet. These activities include Planning, Delivery, Operations, Maintenance, and Disposal.

This document has been developed based on good practice guidance from internationally recognised sources, including BSI PAS 55:2008.

1.2 Scope

The scope of the strategy includes the following cable assets:

- medium-voltage (MV)[1] power cables
- HV[2] power cables
- cable accessories, such as terminations and joints.

Exclusions

The HVDC submarine cables and cables within HVDC related switchyards are excluded from this strategy. These are included in the HVDC Fleet Strategy.

1.3 Stakeholders

Correct installation, operation and maintenance of power cable assets are essential for the safe and reliable transport of electricity. Key stakeholders involved in managing these assets include:

- associated Transpower groups: Grid Development, Performance and Projects
- Commerce Commission and Electricity Authority
- service providers
- customers, including distribution network businesses and generators
- network utilities that share network routes

[1] 1 kV – 72.5 kV inclusive (IEEE definition); safety manual definitions remain separate.
[2] 72.5 kV – 230 kV (IEEE definition); safety manual definitions remain separate.

- local authorities
- New Zealand Transport Agency (NZTA).

1.4 Strategic Alignment

A good asset management system shows clear hierarchical connectivity or 'line of sight' between high-level organisation policy and strategic plan, and the daily activities of managing the assets.

This document forms part of that connectivity by setting out our strategy on the management of power cables and cable terminations. This strategy directly informs the power cables Asset Management Plan, which includes more detail on the timing and quantities of specific capital works to be carried out in the near term.

This hierarchical connectivity is represented graphically in Figure 1. It indicates where the fleet strategy and plan fit within our asset management system.

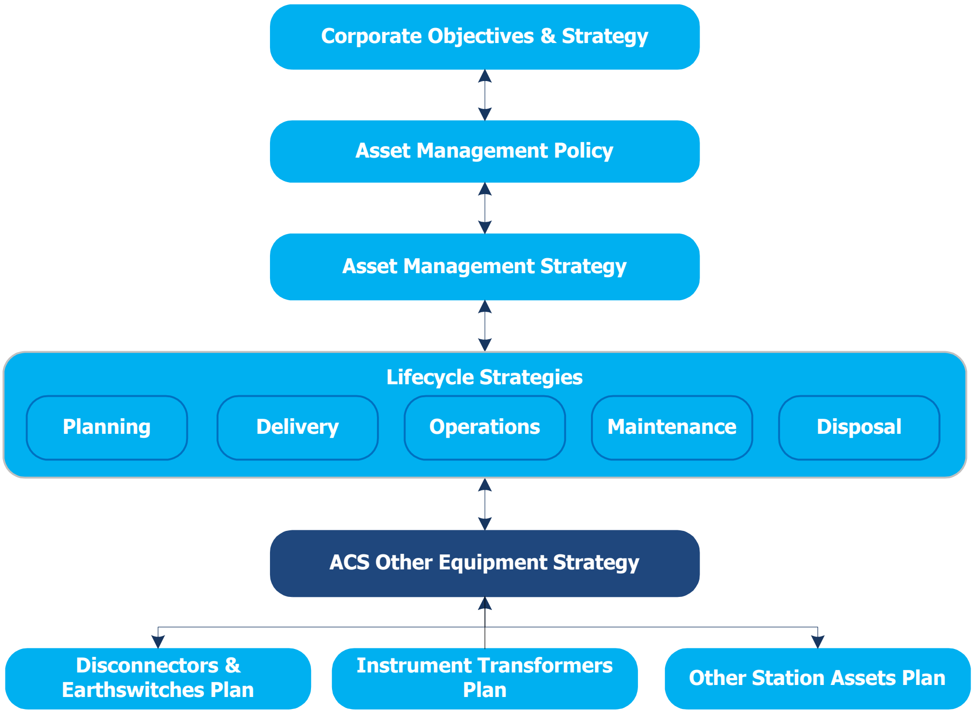

Figure 1: Position of cables strategy and plan within our Asset Management Hierarchy

1.5 Document Structure

The rest of this document is structured as follows.

Chapter 2 provides an overview of power cable assets including fleet statistics, characteristics and their performance.

Chapter 3 sets out asset management related objectives for the assets. These objectives have been aligned with the corporate and asset management policies, and with higher-level asset management objectives and targets.

Chapter 4 sets out the fleet specific strategies for the management of the assets. These strategies provide medium-term to long-term guidance and direction for asset management decisions and will support the achievement of the objectives in chapter 3.

Additional appendices are included that provide further detailed information to supplement this fleet strategy.

2 ASSET FLEET

Chapter 2 provides a high-level description of our power cable assets, including:

- **Asset statistics:** including population, diversity, age profile, and spares;
- **Asset characteristics:** including safety and environmental considerations, asset criticality, asset condition, and maintenance requirements, and interaction with other assets
- **Asset performance:** including reliability, safety and environmental
- **Risks and issues**.

2.1 Asset Statistics

This section outlines our power cables fleet, along with their diversity and age profiles.

2.1.1 Asset Population

The power cable fleet is split into two categories: Medium Voltage (11 kV – 72 kV) and High Voltage (>72 kV). These two populations of power cables are described below.

Medium-voltage cables (11 kV – 72 kV)

The majority of our power cables operate at 11 kV and 33 kV. These cables are of relatively short lengths (most less than 200m long) and are laid inside substations either directly in the ground or in ducts.

The majority of MV cables are copper conductor, with the remainder being aluminium conductor. Paper insulated lead sheathed cables (PILC) were installed up until the mid-1970s. Since then, we have used cross-linked polyethylene (XLPE) insulation with heat shrink terminations for the majority of new and replacement cables. XLPE cables now constitute the majority of the MV cable population. Table 1 gives an overview of the population of MV cable circuits.

Conductor Type	Insulation Type	11 kV	33 kV	50–66 kV	Total
Aluminium	PILC	3	2		**5**
	XLPE	60	134	6	**200**
Copper	PILC	17	41		**58**
	XLPE	402	387	9	**798**
Total		**482**	**564**	**15**	**1,061**

Table 1: Number of MV Cable Circuits – Population[3]

MV cable terminations

We currently have approximately 2,120 MV cable terminations. The planned installation of new switchgear and supply transformers over the next 10 years will lead to more than 500 additional cable terminations installed every year. Some of the existing power cables and

[3] Most of our MV cables are short in length (that is, less than 1 km). Therefore the data is given here in terms of number of circuits instead of length to better describe the fleet population.

terminations will be replaced as a part of other projects, including transformer replacements and outdoor to indoor conversions. The various types of cable terminations we use for MV cables are described in Appendix A.

High-voltage cables (72.5 – 230 kV)

The higher rated cables, 72.5 kV and above, are used within stations as well as between stations. When used outside a station boundary they have individual route lengths of up to several kilometres, and are either directly buried or installed in ducts and cable tunnels. We have approximately 3.6 km of 110 kV and 220 kV oil filled paper insulated lead sheathed cables (OF PILC) dating from the period 1974 to 1985 and approximately 265 km of 110 kV and 220 kV XLPE cables from the period 1990 to 2013. The most recent HV cables are between Auckland substations and were installed as part of the North Island Grid Upgrade (NIGUP) and North Auckland and Northland (NAaN) projects. These new 220 kV cable circuits have provided major enhancements to the security of supply to Auckland, North Auckland and Northland.

Table 2 gives an overview of our shorter (<1 km) HV cable circuit population.

Conductor Type	Insulation Type	110 kV	220 kV	Total
Aluminium	OF PILC	3	3	**6**
Copper	OF PILC	0	5	**5**
	XLPE	22	14	**36**
Total		**25**	**22**	**47**

Table 2: Number of Short Length HV Cable Circuits (<1 km) – Population

The 220 kV and 110 kV transmission cable circuits exceeding 1 km in length are shown in Table 3 below:

Cable Asset	Voltage (kV)	Length (km)	Type
OHW-OTA	220	1.5	1200mm^2 Cu XLPE
BHL-PAK A & B	220	11.5	2500mm^2 Cu XLPE
PAK-PEN A	220	8.6	2500mm^2 Cu XLPE
PEN-HOB A	220	9.3	2500mm^2 Cu XLPE
HOB-WRD A	220	9.8	2500mm^2 Cu XLPE
WRD-ALB A	220	8.5	2500mm^2 Cu XLPE
OTA-PEN 2	110	2.7	1000mm^2 Cu XLPE
OTA-ROS 1 & 2	110	2.7	400mm^2 Cu XLPE
ALB-HEN 1 & 2	110	2.3	400mm^2 Cu XLPE

Table 3: HV Transmission Cable Assets

HV cable terminations and associated equipment

Table 4 and Table 5 give an overview of the HV cable accessories asset population:

Termination Type	220 kV	110 kV	Total
Outdoor Terminations	68	141	**221**
Oil Immersed Terminations	15	9	**24**
GIS terminations	51	0	**51**
Total	**134**	**150**	**296**

Table 4: Number of single phase HV Cable Terminations – Population

Equipment	220 kV	110 kV	Total
Joints (single phase)	243	15	**258**
Link Boxes	50	51	**105**
Oil Tanks	7	3	**10**

Table 5: Number of HV Cable Accessories - Population

DTS systems

DTS systems are relatively new technology that provides cable temperature monitoring capability to identify 'hot spots' along a power cable route.[4]

We have implemented DTS systems on our most critical and long length HV cable circuits. The most recent DTS systems installed were alongside the 220 kV cables as part of NAaN project. We have a total of 4 DTS systems.

HV resonant test set

We purchased a HVAC variable frequency resonant test set in 2008 that has since been used to undertake off-line HV pressure tests, and is also equipped with a limited PD measurement ability. During the pre-commissioning for the recently installed 220 kV and 110 kV cables additional hardware was used to perform concurrent PD measurements at all cable joint and terminations.

This test set was most recently used (April 2013) to test the new 220 kV cable circuit between Albany and Wairau Road substations as part of the NAaN project. The HVAC test, with simultaneous PD measurements, was performed to ensure the integrity of the 12 joints, along 8.4 km lengths of power cable, and the terminations at Albany and Wairau Road prior to connection to the Grid.

2.1.2 Fleet Diversity

Diversity of power cables and cable terminations is a significant asset management consideration. Depending on the manufacturer, cross section area, type of terminations and materials used, each type of cable/termination will require different knowledge and skill sets, as well as physical tools, for their installation, repair and maintenance.

4 For more information, see subsection 2.2.6 for more information about this technology.

Table 6 sets out the diversity of the power cable fleet.

	Number	Comments
Manufacturers	13	For future MV installations we currently have two preferred cable suppliers.
Insulation Types	2	Predominantly XLPE type with the remainder being PILC/OF-PILC types.
Conductor Types	2	Predominantly copper material with the remainder being aluminium.
Conductor cross sectional area	29	Dependant on the rating required and the thermal surroundings of the cable circuits, this varies from 16mm^2 to 1000mm^2.
Termination Types	6	Depending on connection point to primary plant: outdoor, indoor, oil filled, gas insulated switchgear (GIS), heat shrink and cold shrink terminations.

Table 6: Power Cable Fleet Diversity

The HV power cable fleet is significantly more diverse than the MV power cable fleet as these assets are bespoke and unique depending on the manufacturer that we have procured them from. In most cases, spares/parts are not interchangeable between the HV cable assets.

Diversity is not as huge an issue for the MV cable fleet as new MV cables can be manufactured in a relatively short period of time to replace cables that have had a fault.

2.1.3 Age Profile

MV power cables have been installed in substations on an ongoing basis, with a particularly large amount installed between 2000 and 2010. The HV cables were installed in between 1973 and 1983, in the 1990s, and in 2012 and 2013.

Figure 2 shows the age profile of our MV and HV power cable fleet is by conductor and insulation type.

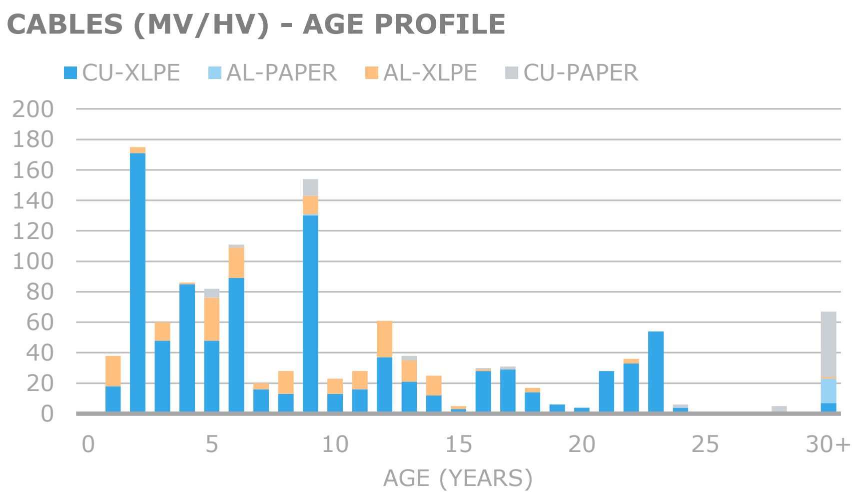

Figure 2: Cables – Age Profile

MV cables

The average age for each type of power cable is shown in Table 7.

Conductor Type	Insulation Type	11 kV	33 kV	50-66 kV
Aluminium	Paper	30	43	-
Aluminium	XLPE	11	8	2
Copper	Paper	17	27	-
Copper	XLPE	12	8	16

Table 7: MV Cables – Average Age

Life expectancy is typically in the range of 50–55 years and is interpreted as the nominal life established for fixed asset accounting purposes. It represents the typical average life that is expected from a type of equipment before it is no longer fit to remain in service. With careful stewardship, longer life can be achieved and the provision of spares allows us to manage the risk of extended outages when a cable failure occurs.

HV cables

The average age for each type of HV power cables is shown in Table 8. It shows that the population of copper XLPE cables (which represent the majority of HV cables) are generally quite young – with average ages of the 110 kV and 220 kV populations at 12 years and 2 years respectively.

Conductor Type	Insulation Type	110 kV	220 kV
Aluminium	Paper	39	30
Copper	Paper	-	31
Copper	XLPE	12	2

Table 8: HV Cables – Average Age

2.1.4 Spares

To align with good industry practice, we aim to be able to restore full security of supply within one calendar month of a power cable failure occurring. This is dependent on the availability of spare cables and the fault location. We are currently reviewing our holdings of spare cables and our repair response capability.

MV power cable spares and other accessories

We currently do not stock MV XLPE cable spares, as these cables and their associated accessories are readily available in the market. Our cable suppliers have cable manufacturing plants in New Zealand and they manage stock levels by ordering replacements when their minimum levels are reached. The estimated procurement and delivery period for an MV XLPE cable is less than a week.

HV power cable spares

For recent HV power cable installations, manufacturer spares have been procured as part of the project. Further details are provided in Table 13 of Appendix D.

HV oil-filled cables are inherently old technology and are no longer readily available in the market. We still have 8 220 kV oil-filled cable circuits in service and it is essential that we retain spares for these circuits (pending replacement). A summary of the spares available for these cables is set out in Table 9.

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Site Name	Cable Spare	Joint Spares (No.)	Termination Spares (No.)	Other Spares
Bream Bay Substation	75m	2 x Straight through joints	1 x Transformer sealing end and 1 x SF_6 sealing end	2 x oil tanks and various pressure gauges
Wilton Substation	230m	1 x Straight through joint	1 x Transformer sealing end and 1 x SF_6 sealing end	1 x oil tank and pressure gauge
New Plymouth Substation	To be assessed[5]	To be assessed	To be assessed	To be assessed
Rangipo Substation	347m[6]	See footnote 6	See footnote 6	See footnote 6

Table 9: HV power cable spares

2.2 Asset Characteristics

The fleet of power cables assets can be characterised according to:

- safety and environmental considerations
- asset criticality
- asset condition
- maintenance requirements
- interaction with other assets.

These characteristics and associated risks are discussed in the following sections.

2.2.1 Safety and Environmental Considerations

We are committed to ensuring that safety and environmental risks are minimised at all times as reflected in the objectives in chapter 3. The most significant safety and environmental considerations for the power cable fleet are:

- accidental damage when excavating, especially by third parties in public places
- failure to identify and isolate live cables correctly before commencing work
- fire resulting from cable failure
- explosive ejection of debris from failing cable terminations, particularly those with porcelain insulators
- work in confined spaces when installing and accessing cable installations, especially in tunnels and basements
- Earth Potential Rise (EPR) and transfer hazards
- close proximity exposure to an insulation failure due to an ability to closely approach adjacent live circuits
- oil leaks.

These issues are described below.

5 The New Plymouth spare cable was found to be in an un-serviceable condition and has since been scrapped.
6 These are two de-energised single phase spare cables that run in parallel with the in-service cable circuits with completely installed bushings and terminations ready to be connected to the GIS should the need arise.

Accidental damage when excavating

The greatest risks arising from a cable installation are the hazards created by a cable being damaged as a consequence of third party activities (such as excavations that disturb/damage the cable), especially if they are not aware that a cable is located where they are excavating.

If someone is in an excavation when the cable is damaged or the insulation fails, then the consequence can be catastrophic. There can even be serious injury for those outside the excavation.

There are also industry guidelines for digging in the vicinity of live services. We also subscribe to the 'Dial Before U Dig' system for preventing and reducing risk of damage caused by third parties.

Failure to identify and isolate live cables correctly before commencing work

Should a live cable be incorrectly identified by a cable jointer tasked with working on a cable, the consequences can be severe and catastrophic. The jointer may be badly injured and the circuit affected is often the one the system is reliant upon, causing a loss of supply with very long restoration times.

It is critical that there is rigid adherence to cable identification procedures prior to commencing work on any cable.

Fire resulting from cable failure

When cable insulation fails, there is normally an arc flash and a resultant fireball resulting from the ejected materials. In the case of oil-filled cables this can be especially severe because the oil, being pressurised, continues to feed the fire. As the failed cable contains many flammable elements, it can become a source of fuel for a continuing fire (or trigger a fire in adjacent combustible materials). It is this continuing fire that presents a safety risk to people and equipment.

It is important that cable installation design considers and appropriately mitigates fire risks from potential cable failure.

Debris from falling cable terminations, particularly those with porcelain insulators

When a cable termination (with porcelain insulator) fails, there is the potential for an explosion that causes the insulator to shatter and eject debris over a large area. New designs use composite components that reduce this risk considerably.

Work in confined spaces including tunnels and basements

Working on cable systems inevitably leads to circumstances where workers are required to enter areas deemed to be confined spaces. It is recognised that cable tunnels can be hazardous to personnel and the conditions onerous for ancillary equipment. It is advantageous to restrict personnel access to cable tunnels as much as possible. When access is required, this is carried out in a structured manner using well-maintained equipment. The principal risks are fire, smoke inhalation, toxic gases, explosive failure of the cable, and the absence of permanent lighting. Being situated below ground level, cable tunnels can fill with dense gases, which can cause asphyxiation.

The following are current mitigations that we have adopted.

- Controlled process by risk assessment of activities in confined spaces, development and application of best practise risk controls.

- New transformer cable box designs have split gland plates which allow the gland plate to be temporarily removed during the installation. This allows the cable ends to be moved out from the confined space.
- Insistence on good practice in creating a safe work area, such as keeping the work area tidy.
- Making sure that there is a fire extinguisher close to the work area.
- We are currently looking at alternative cable termination types that do not require the use of flame torch for installing the cable termination or joint.

For additional details see our service specification 'Confined Space Entry Requirements for Transpower Sites', TP.SS 06.18.

Earth Potential Rise transfer

Cable construction calls for an earth screen and / or metallic sheath around the cable insulation. However, certain situations at points where the cable sheath is earthed can create dangerous levels of step and touch potential that pose a risk to workers, adjacent utilities and members of the public, predominantly during fault events.

It is important that cable earthing design is carried out and verified by competent and experienced professional service providers, in line with New Zealand regulations.

Exposure to magnetic fields

The metal sheath surrounding cables means that there is no electric field beyond the cable. However, a magnetic field does extend beyond the cable. Depending on the location of the cable, maintenance contractors and the general public can be exposed to the magnetic field.

Magnetic fields have been shown to cause hair movement, magnetophosphene effect,[7] and microshocks. These are legitimate effects in themselves, and could also lead to other safety hazards for maintenance contractors distracted by these effects during important tasks. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has set guidelines to avoid these effects, which are adopted in New Zealand regulations. We follow the guidelines when designing new assets and use them as the basis for electric and magnetic field training for maintenance workers to help them reduce their exposure.

Personnel exposed to cable insulation failure

In general, cable circuits (excluding terminations) can be safely approached within the minimum approach distance for conductors in air due to the cable insulation. Yet there is a risk that cable insulation failure can cause serious harm to nearby personnel and those working on the cable.

The probability of a cable insulation failure is very low. Also personnel who are 'competent to work in the vicinity of live cables' will be trained and experienced to assess and manage the risks posed by being in close proximity to live cables.

Environmental

Reduced environmental impact

The use of underground power cables rather than overhead lines to carry a transmission circuit reduces the visual impact of the transmission system. It may also reduce the

[7] Magnetophosphene involves a temporary flickering in the peripheral vision.

electromagnetic fields in the vicinity. Accordingly, underground power cables are a favoured option for increasing capacity or replacing lines in densely populated areas.

Yet the use of cables in public spaces does have civil and landscaping effects, principally due to the inability to dig into the area after the cable has been laid.

Oil leaks

We still have a small number of oil-filled HV power cables in service. The insulation in oil-filled cables is impregnated with oil that is fluid at all operating temperatures and is always under positive pressure to ensure all voids within the insulation are filled in all operating conditions.

Degradation of oil-feeding equipment or the cable itself can lead to oil leakage. This has the potential to impact the local environment.

2.2.2 Asset Criticality

We have established a process to determine asset criticality based on consideration of the importance of the site. This is based on factors, including load served, level of redundancy and consequence of a failure. Based on these factors we have established a framework for assigning Asset Criticality, which classifies all assets as high, medium or low impact. For further details, see the 'Asset risk management – Criticality framework' document.

Asset management is adapted to recognise the differing levels of criticality to mitigate the risk of failures at critical sites and corridors and to allow less capital expenditure on assets that are less critical. The strategies in chapter 4 demonstrate how we take account of criticality, particularly through earlier or later replacement and more or less frequent maintenance.

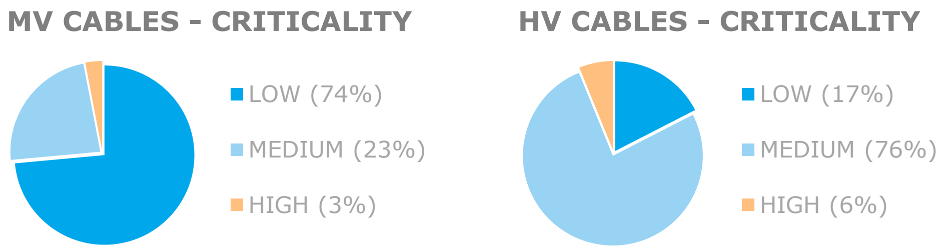

Figure 3: Cables – Criticality

The chart for HV cables in Figure 3 shows that the majority (82%) can be classified as either medium or high criticality assets.

2.2.3 Asset Condition

Condition assessment of power cables and their associated terminations can be particularly challenging because it is not possible to directly observe the internal condition of the cable (such as the insulation or conductor). While qualified assessment of the exterior condition of a cable or termination can provide some useful condition information, this is limited for buried cable installations.

MV cable – condition

Most of our MV XLPE cables were recently installed and are in good condition. There is some legacy MV PILC cables that have had moisture ingress and poor workmanship issues which have led to sheath/termination failures.

HV cable – condition

All of our HV XLPE cables have been installed recently and are deemed to be in good condition. However, we still have 8 (legacy) oil-filled HV cable circuits in service at BRB, WIL, NPL and RPO substations which are in various conditions as outlined in Table 10.

Substation	Condition Assessment
Bream Bay	Condition assessment was carried out in 2012: the T2/T3 cables showed cracks in the oversheaths and a minor leak was identified in the oil tank. Further details are provided below.
Wilton	Cables are generally in good external condition, but recording of condition assessment information will be reviewed and improved. The next condition assessment is due in RCP2.
New Plymouth	Cables are generally in an acceptable external condition, but recording of condition assessment information will be reviewed and improved. The next condition assessment is due in RCP2.
Rangipo	Condition assessment was carried out in 2012: All cables were in good condition, but recording of condition assessment information will be reviewed and improved.

Table 10: HV Oil-filled cables condition

During routine maintenance carried out on the 28-year-old Bream Bay oil-filled cables in 2012, it was found that the cable over-sheath showed signs of cracking and deterioration. Further inspection of these cables found that the heat shrink covering the lead plumb has split on two phases of one cable circuit and there is a difference in cable fluid pressure between the phases. These issues were subsequently repaired and electrical, residual gas pressure and dissolved gas analysis tests were carried out to confirm the integrity of the oil-filled cable. The next condition assessment is expected to be carried out in RCP2. It is expected the condition of these cable will have deteriorated by the end of RCP2 as they are nearing their expected end of life.

2.2.4 Maintenance Requirements

This subsection describes the maintenance activities undertaken on the power cable fleet which informs the maintenance strategies (section 4.4). The most common types of maintenance carried out on power cables assets are:

- preventive maintenance, including:
  - condition assessments
  - servicing
- corrective maintenance, including:
  - fault response
  - repairs
- maintenance projects.

The Maintenance Lifecycle Strategy provides further details on our approach to the above maintenance works.

Condition assessments

Modern cables are designed to be low maintenance, following rigorous pre-commissioning tests. Once in service, the generally accepted approach to the maintenance of cable assets is to undertake time-based maintenance and condition assessment (followed by adequate action as required, to avoid failure in service).

A number of diagnostic condition tests can be carried out on the MV and HV power cables, at varying intervals. These tests are summarised below.

- Assess whether the outer plastic coating (sheath) of the cable remains intact. Generally manufacturers recommend this be undertaken annually. If the test indicates the sheath has been compromised, then the area of damage will be located and a repair effected. Damage to outer sheaths risks moisture ingress that can lead to premature failure.
- Undertake PD measurements of circuits, with a particular focus on the joints and terminations. Increasing trending levels of PD can indicate degradation in the insulation and are a potential pre-cursor to failure. This is a complex area and the interpretation of the results requires specialised skills.
- Do oil sample tests on the oil-filled cables. A sample of cable oil is drawn from the circuit and is subjected to various analytical tests that give an indication of dissolved gas. Over time it is possible to discern trends that could indicate degradation. Quantifying the degradation[8] can be quite difficult and the decision to flush the cable with new oil will be assessed on a case-by-case basis.
- Visually inspect (primarily link boxes) the cable circuit bonding systems to ensure there is no corrosion or water ingress.

Maintaining MV and HV cables

While some maintenance tasks are common to both extruded and oil-filled cables, there are different practices for extruded and oil-filled cables, respectively.

XLPE cables

Fewer maintenance tasks are carried out on XLPE cables compared to oil-filled cables. The most common maintenance tasks carried out for extruded cables are outer sheath testing (sheath test) and visual inspection of terminations.

The sheath test indicates if the sheath is damaged. The damaged sheath is located and repaired (when a suitable outage on the cable circuit is available). A sheath repair will stop further ingress of water and preserve the life of the cable. Another commonly used test is visual inspection of the terminations. This can indicate the early stages of leakage from terminations and other failures, which can eventually lead to breakdown.

The more recently installed 220 kV circuits can be monitored thermally using the DTS system described previously in subsections 2.1.1 and 2.2.6.

[8] This is similar to power transformers dissolved gas analysis where each test has a unique profile as the rate of gas generation is dependent on the load, transformer design and age.

Oil filled cables

For oil-filled cables (as with extruded cable), the maintenance process primarily consists of sheath tests, visual inspection of terminations and temperature/oil pressure monitoring.

A visual inspection is carried out on the terminations in substations and also other equipment such as oil feed tanks.

The pressure in the cable system is monitored and there is an alarm system to indicate if the pressure is too low. Periodic checking of the alarm equipment and control of pressure level is part of the maintenance procedures. By monitoring the pressure it is possible to identify oil leaks at an early stage and minimise the environmental effects of an oil leak by carrying out a repair as early as possible. When the leakage rate reaches a certain level, it is necessary to locate the leak and repair the cable, generally during a planned outage of the cable circuit.

Historic spend

The average historic spend for the last five years for power cables preventive maintenance and corrective maintenance is approximately $150k each or $300k in total per year.[9]

Maintenance projects

Maintenance projects typically consist of relatively high-value planned repairs or replacements of components of larger assets. Maintenance projects would not be expected to increase the original design life of the larger assets. Maintenance jobs are typically run as a project where there are operational and financial efficiencies from doing so.

Maintenance projects are usually planned at least 12 months in advance, and are often part of a long-term strategy for a particular fleet of assets. Maintenance projects are included in the integrated works planning process and are supported by individual business cases.

Currently a number of minor maintenance projects are being undertaken in RCP1 for the cables fleet, including replacing MV cable terminations. We intend to undertake major repairs for the 220 kV oil-filled cables in RCP2, see subsection 4.4.3 for more details.

2.2.5 Interaction with Other Assets

Power cables connect to a large range of equipment, and programmes of work for power cables are closely aligned with work on other assets on the Grid including:

- buses and circuit breakers
- transformers
- outdoor 33 kV switchyards
- indoor switchgear.

As described in subsection 4.1.2, power cables are required for some large enhancement and development projects as well as other projects funded by third parties, particularly property developers. In these cases, the expenditure is not included under the power cables portfolio as it is included in the major project plan.

9 The historic costs do not reflect the costs of undertaking frequent route patrols of the cable route for the recently installed 220 kV cables in the Auckland region. So it is expected that future maintenance costs will exceed historic costs.

An Integrated Works Planning (IWP) process allows for coordination across asset works to minimise disruption and reduce costs.

2.2.6 Emerging Technologies

Continuous developments are being made in electricity transmission equipment, which provide opportunities to improve service to customers. To capture the opportunities without accepting undue risk, we undertake a conservative approach to new technology by developing a thorough understanding of the technology, including its benefits and risks, and testing the technology on the Grid. The following discusses Distributed Temperature Systems – new technologies that we are appraising for deployment within the power cables fleet.

Distributed temperature systems

An important consideration in power cable asset management is the ability to identify hot spots along the length of a power cable. For long lengths of buried power cable, there are many unknowns along the cable route. These can include soil thermal resistivity variations, soil moisture content, and ambient temperature variations. Soil testing can limit these unknowns to a certain extent. Yet these tests are usually only carried out on a few sample locations along the route, during the initial installation phase due to practicalities, and may not be representative of the entire route. In addition, the environment around the cable installation will invariably change over its working life, from causes such as the installation of other buried services, road widening, changes of ground levels, and so on.

One method to analyse and determine cable hot spots is to use DTS systems which consist of optical fibre cables, associated controllers and sensors. Optical fibre cables are used because temperature can affect the glass fibres and locally change the characteristics of light transmission in the fibre. This is known as the light scattering or 'Raman' scattering effect. Optical modules, such as lasers and sensors, then measure the light scattering and the temperature along the fibre can be derived from these measurements. Therefore an optical fibre cable can be installed alongside a power cable to measure the cable sheath temperature along its length.

Another advantage of DTS systems is the ability to provide an input to real-time dynamic cable rating (DCR) software. We are currently investigating the application of such DCR software to provide this dynamic rating capability for our 220 kV NIGUP & NAaN cable circuits.

The DTS systems are new technology and are relatively complicated systems that require close attention to ensure satisfactory operation.

2.3 Asset Performance

This section describes the historic reliability, and safety and environmental performance of power cable assets together with any associated risks and issues.

2.3.1 Reliability

Achieving an appropriate level of reliability for our asset fleets is a key objective for us as it directly affects the services received by customers. Reliability is measured primarily by the frequency and length of outages.

MV cables and terminations

Failures due to moisture ingress

We have had a number of failures on outdoor MV PILC cable terminations due to moisture ingress. These failures were found to have been caused by the use of incorrect cable lugs, and defective termination seals due to improper installation. Table 11 shows the failures due to moisture ingress.

Device Position	Date of Fault	Fault Location	Voltage (kV)	Cable Type	Installed	Years Before Failure
WDV-CBL-1006	Jan-09	T1 Outdoor	11	PILC	January 1994	15.0
OTA-CBL-39	Feb-09	T12 Outdoor	22	PILC	May 1992	16.8
ALB-CBL-912	Jan-05	C4B Outdoor	11	PILC	January 1981	24.0
WHI-CBL-32	Sep-08	T3 Outdoor	11	PILC	October 1983	24.9

Table 11: Cable Failures Due to Moisture Ingress

After these failures, other PILC cables that have the same cable lugs/seals were identified and in 2009 we released service advisory TP.SS 02.46 SA1 to rectify this issue. These cable terminations were replaced with the proper cable lugs and seals. We have not had any further PILC cable termination failures that can be attributable to moisture ingress.

Failures caused during installation of cable terminations

We began installing a specific 33 kV type of heat shrink indoor/outdoor termination, made by a well-known manufacturer, from 2001. There has been a high rate of failure of this particular type of MV cable termination in the period 2001 to 2012. 85% of these failures have been identified as caused by poor workmanship during installation. Investigation into these failures has also highlighted a number of other concerns that are described in subsection 2.3.4. Up to 200 cable circuits may be at risk from termination failures resulting from poor workmanship. See Appendix C for details of the major issues and failures of this particular type of MV cable termination.

Failure trends

Figure 4 shows MV cable failures between 2003 and 2012.

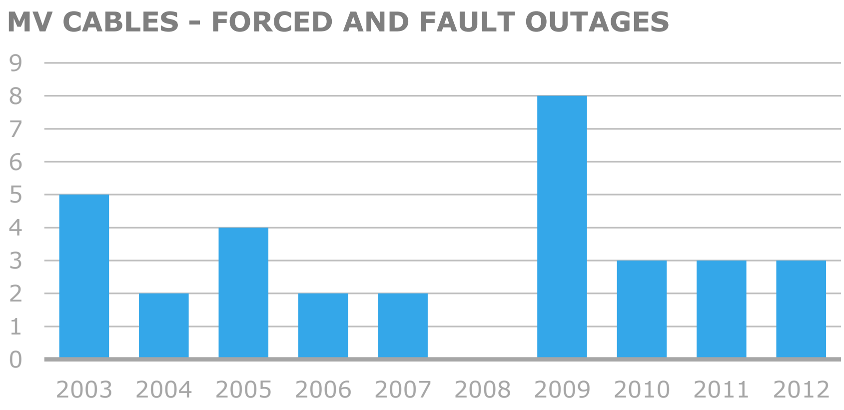

Figure 4: MV Cables - Forced/Fault Outages

The main causes of outages associated with these failures are poor workmanship on cable joints and terminations, faulty cables and terminations. We are seeking to address these causes through the strategies outlined in chapter 4.

HV cables and terminations reliability

There has been one 220 kV joint failure recently, which occurred during the initial commissioning process, which was found to be due to the splitting of an internal component. The entire phase was replaced, at the supplying contractor’s expense and was subsequently commissioned successfully.

A separate issue was identified with one of the NIGUP 220 kV circuits during the maintenance testing. A section of the cable circuit is installed in a tunnel and the roof at one location was found to be leaking onto one of the cable joints. A sheath test was undertaken and this highlighted water ingress. An outage was scheduled to undertake a repair and the tunnel structure was enhanced to protect the cable from further water ingress.

2.3.2 Cost Benchmarking

We have been involved in the International Transmission Operations & Maintenance Study (ITOMS) since 1994 to identify areas for performance improvement. However, as ITOMS does not specifically cover power cables, we have not made a full benchmark comparison of the performance and maintenance cost of our power cable fleet. Based on anecdotal evidence, our performance and costs appear similar to networks overseas.

2.3.3 Safety and Environmental Performance

Subsection 2.2.1 described issues with power cables assets that impact safety and environmental performance. This subsection reports on the actual safety and environmental performance of the fleet.

Safety

We have not experienced public or operator injuries or fatalities attributable to power cables in the past 20 years. However, there have been a number of lost time injuries during the installation of the various large 220 kV cable projects undertaken recently in the Auckland area. These have been attributable to poor site management and supervision rather than specific to power cables technology of itself. The most serious of these incidents resulted in short periods of hospitalisation.

Environmental

The only environmental incidents have been a number of minor oil leaks from cable sealing ends, but all were contained within our controlled sites.

2.3.4 Risks and Issues

This subsection briefly discusses the most significant risks and issues facing the asset management of the current population of power cables. The strategies to mitigate the risks below are set out in chapter 4.

Critical loads and long recovery times

As outlined in subsection 2.2.2, many of the HV cable circuits are of medium or high criticality. One notable example is the oil-filled 220 kV cable circuits at Bream Bay that supply the New Zealand Refinery at Marsden Point. A further example is the oil-filled 220 kV cable circuits at Wilton that are essential to the supply to a large part of central Wellington. In both cases, the cables provide a direct connection between indoor gas insulated switchgear (GIS) switchgear and the supply transformers. The cable connections use sulphur hexafluoride (SF_6)-to-oil bushings at the GIS end, and oil-to-oil bushings at the power transformer end. In both cases, if a cable or termination fails, there is currently no readily available bypass solution to promptly restore full security.[10]

A cable failure would place nationally significant loads on ‘N’ security for a lengthy period while the fault is repaired or the cable replaced. The probability of a total loss of supply to these nationally significant loads is greatly increased while one cable circuit is out of service undergoing repair or replacement.

HV testing of legacy cable circuits

Ideally, the condition of legacy oil-filled HV cables such as those at Bream Bay and Wilton would be confirmed using high-voltage separate source testing with PD measurements at the cable terminations. However, such tests are particularly difficult to undertake, because of the need to fit temporary SF_6-to-air test bushings into the GIS switchgear, and the need to break connections in oil junction boxes in the power transformers, before a test can be conducted. Further, the interpretation and assessment of PD test measurements may be problematic.

Field testing of these cable circuits is difficult and costly, and entails a considerable degree of risk. It also requires the operational circuit to be removed from service for an extended period. For these reasons, separate source pressure testing of HV cable circuits is often only undertaken at the time of original commissioning.

Lead time for HV cables repairs

For repairs to HV cables, overseas cable manufacturers usually provide an emergency repair service. There are specialists in Australia who are available at reasonably short notice, depending on their prior commitments. Cable repairs require spare lengths of cable, spare

[10] At Wilton, there is a spare 110/33 kV transformer that can be used to partially restore security to the 33 kV busbar in the event of a major failure of a 220 kV cable or supply transformer

cable joints and spare terminations to be on hand. This reliance on the manufacturers, coupled with the possible need to undertake excavation works, represents a risk in that repair times can be up to 8 weeks.

As previously mentioned in subsection 2.1.4, the 220 kV oil-filled cables are considered to be an obsolete technology. There has been a rapid decline in the number of suppliers who can manufacture parts or provide technical support. This presents a risk that we may not be able to obtain spare parts. Currently, we have spare HV oil-filled cables (see subsection 2.1.4 for more information) at most of our sites but there is a lack of spare joints and terminations for the New Plymouth substation. There is a risk that repair/outage times may be significant due to the lack of spare parts and/or technical support.

Uncertainty of condition of legacy HV cables

As noted in subsection 2.2.3 and outlined in the topic above concerning HV testing, it can be difficult, costly and often impractical to obtain robust and detailed information about the internal condition of cables. This is particularly the case with cables that terminate directly into GIS equipment or power transformers, rather than air bushings. Asset management decision making must make use of the often limited condition assessment information that is available, but also fully recognise the potentially severe consequences of cable failure.

Accidental damage caused by third parties

As identified in 2.2.1, there is a substantial risk of damage to our power cables by third parties because a number of the cables are outside of our land boundaries. Damage can cause outages and injuries or fatalities. This is most likely to occur by somebody striking the cable with machinery while digging.

Damage caused by earthquakes and ground differential movement

Buried cables may be located in a seismically active area subject to strong ground shaking, or ground deformation such as settlement, liquefaction, landslide, and fault displacement.

As evidenced by the Christchurch earthquake that occurred in 2011, Orion suffered extensive damage to their cable network mainly due to displacement caused by liquefaction induced ground movement.

There is a potential for our critical cable circuits to be damaged significantly in events like these, and prompt restoration of supply may not be possible. Concrete reinforced cable tunnels/troughs or ducts could be installed to house a cable circuit to provide some limited mechanical protection to damage caused by ground movement.

The strategies for responding to cable damage caused by ground displacement are described in subsections 4.3.1 and 4.4.1.

Fire risk

Jointing and terminating cables require cleaning of the cable insulation and various other components. In the cases where the power cable is terminated inside a restricted space (such as in a cable box), there is an element of fire risk to the worker, especially when organic solvents are present in the work area. This has previously happened at an electricity distribution business' substation in New Zealand. An example of a worker installing heat shrink cable terminations in a cabinet is provided in Appendix B.

There is a risk of fire when installing a heat shrink termination in a restricted space. Currently the work requires the use of a solvent to wipe clean the cable insulation prior to using a flame torch to shrink the termination body onto the prepared cable.

Competency

As outlined in subsection 2.3.1, poor installation of one particular type of 33 kV heat shrink cable termination has resulted in a number of cable failures. This highlights a lack of service provider experience in installing this type of termination.

Cable jointing and terminating requires a high level of skill, patience and attention to detail. This is applicable to XLPE-type and PILC-type cables. However, for PILC cables, it requires a completely different set of skills compared to XLPE, such as handling pressurised oil as the insulating medium.

PILC cables were predominantly installed in the 1980s to early 1990s and are still in service. Most of the PILC terminations and joints were installed by the cable accessory supplier and the jointing/terminating skills were not passed on to or retained by our service providers.

In addition to the risk due to the lack of support or supply of these PILC accessories, the skills in jointing/terminating PILC cables are now receding from the electrical industry due to the progressive adoption of XLPE insulation technology.

Jointing and sealing compounds non-availability

When repairing cable joints and sealing ends, the instructions that accompany the equipment usually stipulate that the recommended jointing and sealing materials must be used. However, in many instances the manufacturer’s recommended compounds are no longer available. This requires that when using alternative materials their suitability must be confirmed with the cable or compound manufacturer, as the compounds are designed for particular purposes and voltages.

Power cable vulnerabilities

Cables can be exposed to over-voltages caused by lightning strikes on the adjacent sections of line. Surge arresters are installed for over-voltage protection of the cable insulation; but they do not provide complete protection. Moreover, they may fail while in service.

Cable sections also introduce more components (cable, cable terminations and intermediate joints, surge arresters) and failure modes into the transmission circuit. Failure of any one component will result in a forced outage of the circuit. Cable, termination or joint failures usually result in repair times of several days or even weeks, as compared with less than one working day for most line failures.[11]

[11] Statistically, cables have a lower failure rate than an equivalent length of transmission line.

Asset knowledge

Asset knowledge is a critical input into asset management decisions. While our power cable asset knowledge (such as the power cable age, make/model and known generic issues) is adequate, there are some areas where we can improve. The following are some asset knowledge issues we have currently identified.

- A portion of our asset management database is currently decentralised. In particular, the power cable test results, condition assessment reports and maintenance records are stored electronically on an ad-hoc basis.
- We have a range of service providers for maintenance and it is difficult to ensure a standardised approach in categorising/gathering information into the asset management database.
- We have inaccurate/incomplete records of installation details (such as cable termination manufacturer, pre-commissioning test results and installer details). Improving these records will help in identifying whether there are generic design or workmanship issues.
- Photographic evidence of the external condition of power cables (where possible) is currently lacking and makes it difficult to assess without engaging the maintenance personnel on site.
- Power cable test results, such as PD measurements, oil tests for oil-filled cables and very low frequency tests need to be captured and maintained in the asset management database.
- Information from the DTS should be recorded and reviewed regularly.

Undergrounding for property developers

Land under overhead transmission lines is becoming increasingly valuable, particularly near or inside urban areas. Numerous requests have been received from property developers for sections of overhead line to be either relocated, or converted to underground cable. Several undergrounding projects have been completed, and others are committed.

However, the interests of the property developers are significantly different from ours. The property developer typically seeks the undergrounding project to be completed in the shortest possible timeframe, and for the lowest possible cost. The developer has no interest in the long-term reliability of the transmission circuit, and cannot realistically be assigned any liability for the performance of the underground cable segment. Other issues that can arise with these projects relate to the procurement of easements for the cable route, and ensuring ongoing access.

Uncertainty in thermal rating of cables

The ampacity or rating of a cable is limited by the maximum allowable temperature of the insulation material. The cable heats up due to insulation losses, loading and in some occasions other nearby heat sources during normal operation. Most cable installations are buried installations and the surrounding soil acts as an insulating layer for heat dissipation, which has a significant impact on the cable rating. To maximise heat dissipation, thermally stabilised backfill is often used and sized appropriately to optimise cable size, installation costs and electrical requirements such as magnetic field intensity or voltage drop.

Yet cable backfill designs are often conservative, as it is very difficult to assess the changes to the thermal environment of the cable surroundings. This is mainly due to not being able to directly measure the temperature of a power cable by conventional methods or observe changes to the cable backfill material and surrounding native soil. These changes to the thermal environment could be brought about by:

- a significant change in weather patterns (such as ambient temperature rising above expected conditions)
- cable backfill being contaminated or replaced with an inferior material by a third party without our knowledge
- presence of air pockets or dry cracks in backfill material due to ground displacement
- asphalt or other high thermal resistivity materials being installed over part of the cable route
- heat sources, such as other power cables or pipes, being installed nearby the cables without our knowledge.

All these factors can lead to uncertainty in the maximum allowable rating of the cable circuit.

In our critical cable circuits, such as the 220 kV NAaN and NIGUP cables, we have installed DTS equipment to allow us to monitor for cable ‘hot spots’ and to minimise the uncertainty with the cables’ thermal environment. The DTS system is described further in subsection 2.2.6.

3 OBJECTIVES

Chapter 3 sets out asset management related objectives for our power cable fleet. As described in section 1.4, these objectives have been aligned with our corporate management objectives, and higher-level asset management objectives and targets as set out in the Asset Management Strategy.

Our power cable fleet overarching vision is to achieve sustainable performance consistent with customer requirements and to minimise whole-of-life costs. Further objectives have been defined in the following five areas.

- Safety
- Environmental and stakeholders
- Network performance
- Cost performance
- Maturity and capability.

These objectives are set out below, while the strategies to achieve them are discussed in chapter 4.

3.1 Safety

We are committed to becoming a leader in safety by achieving injury-free workplaces for our employees and to mitigating risks to the general public. Safety is a fundamental organisational value and we consider that all incidents are preventable.

Safety Objectives for the Power Cable Fleets

- No injuries/fatalities resulting from installation or maintenance of cables.
- No fatalities caused by incidents of members of public hitting cables while digging.
- No fatalities caused by cable failures.
- No injuries caused by EPR or transfer of potential on cable screens.

Safety in relation to HV faults is fundamentally about preventing incidents involving HV equipment and where incidents occur, minimising exposure time for employees or members of the public. Protection cannot predict where faults will occur, but the use of appropriate design concepts and technology can reduce injury and chance of death.

3.2 Service Performance

Ensuring appropriate levels of network performance is a key underlying objective. The overall service performance in terms of Grid Performance (reliability) and Asset Performance (availability) are set out in our Asset Management Strategy.

Grid performance objectives state that a set of measures are to be met for Grid Exit Points (GXPs) based on the criticality of the connected load. In addition, asset performance objectives linked to system availability have been defined. These high-level objectives are supported by a number of fleet specific objectives, and we will work towards these being formally linked in the future.

Service Performance Objectives for the Power Cable Fleet

- Fewer than 5 cable faults per year on MV cables (current rate is 3.4 cable faults each year).
- Recovery from major failure of a single MV cable is achieved within one week.
- Zero cable faults on HV cables.

3.3 Cost Performance

Effective asset management requires optimising lifecycle asset costs while managing risks and maintaining performance. We are committed to implementing systems and decision-making processes that allow us to effectively manage the lifecycle costs of our assets.

Cost Performance Objective for the Power Cable Fleet

- Design, construct, and maintain cables to minimise lifecycle costs, while meeting required levels of performance.

3.4 New Zealand Communities

Asset management activities associated with the secondary system fleets have the potential to impact on both the environment and on the day-to-day lives of various stakeholders. Relationships with landowners and communities are of great importance to us and we are committed to using asset management approaches that protect the natural environment.

New Zealand Communities Objectives for the Power Cable Asset Fleets

- No significant oil spills into the environment.
- Magnetic fields caused by cables are within limits specified by the Resource Management (National Environmental standards for the Electricity Transmission Activities) Regulations 2009 (SR 2009/397).
- Maintain effective relationships with stakeholders affected by cable works.
- Asset management approach is effectively coordinated with owners of infrastructure where our cables are installed.

3.5 Asset Management Capability

We aim to be recognised as a leading asset management company. To achieve this we have set out a number of maturity and capability related objectives. These objectives have been grouped under a number of processes and disciplines that include:

- Risk Management
- Training and Competency
- Asset Knowledge
- Continual Improvement and Innovation.

The rest of this section discusses objectives in these areas relevant to the power cable fleet.

3.5.1 Risk Management

Understanding and managing asset related risk is essential to successful asset management. We currently use asset criticality and asset health as a proxy for a fully modelled asset risk approach, and we have developed a number of risk management objectives in our Asset Management Strategy. These objectives are expanded below where relevant to the power cable fleet.

Risk Management Objectives for the Power Cable Fleet

- Emergency preparedness for failures of HV cables is in line with good international industry practice.
- Risk profile of cable installations assessed using non-destructive testing.

3.5.2 Training and Competency

We are committed to developing and retaining the right mix of talented, competent and motivated staff to improve our asset management capability. The asset management strategy has a number of training and competency objectives that apply to employees across the range of skills we require.

Training and Competency Objectives for the Power Cable Fleet

- All persons operating, installing or performing maintenance on cables are adequately trained.
- All persons installing cable terminations are certified as competent.
- Retain access to adequate specialist service providers with the appropriate maintenance knowledge of HV cables and jointing.
- Retain appropriate core capability within our company for long-term asset management of cables.

3.5.3 Asset Knowledge

We are committed to ensuring that our asset knowledge standards are well defined to ensure good asset management decisions. Relevant asset knowledge comes from a variety of sources including experience from assets on the Grid and information from the manufacturers. This asset knowledge must be captured and recorded in such a way that it can be conveniently accessed. The Asset Management Strategy includes overarching objectives in relation to Asset Knowledge.

Asset Knowledge Objectives for the Power Cable Fleet

- Information held about cable assets, including maintenance and condition history is accurate and complete.
- Effective relationships are maintained with cable suppliers.
- Asset condition and performance information is shared regularly with international peers and network operators.

3.5.4 Continual Improvement and Innovation

Continual improvement and innovation are important aspects of asset management. We have specified a number of objectives in relation to continuous improvement and innovation in our Asset Management Strategy.

Continuous Improvement and Innovation Objectives for the Power Cable Fleet

- Maintain an up-to-date understanding of the latest cable termination technology where there are realistic opportunities available.
- Explore the potential and observe the performance of cold-shrink terminations.
- Explore the potential for dynamic rating of critical cable circuits.

4 STRATEGIES

Chapter 4 sets out our fleet-specific strategies for the management of power cables assets. These strategies are designed to support the achievement of the objectives in chapter 3 and reflect the characteristics, issues and risks identified in chapter 2.

The strategies are aligned with our lifecycle strategies below and the chapter has been drafted to be read in conjunction with them.

- Planning Lifecycle Strategy
- Delivery Lifecycle Strategy
- Operations Lifecycle Strategy
- Maintenance Lifecycle Strategy
- Disposal Lifecycle Strategy.

This chapter also discusses personnel and service provider capability related strategies which cover asset knowledge, training and competence.

Scope of strategies

The strategies focus on expenditure that is planned to occur over the RCP2 period (2015–2020), but also include expenditure from 1 July 2013 to the start of the RCP2 period and some expenditure after the RCP2 period (where relevant). Capex planned for the period is covered by the strategies in section 4.1, and opex is mainly covered in section 4.4. The majority of the capex consists of asset replacements as described in subsection 4.1.3.

4.1 Planning

This subsection describes our planning strategies for our power cables fleet.

Planning activities

Planning activities are primarily concerned with identifying the need to make capital investments in the asset fleet. The main types of investment considered for this fleet are enhancement, development, replacement, and refurbishment works.

We support the planning activities through a number of processes, including:

- Integrated Works Planning (IWP)
- cost estimation.

An important planning consideration in regards to the cable fleet is the need for sufficient capacity and flexibility to operate the system in the event of a prolonged unavailability of a cable circuit (as repair or replacement of cables will often take a long time). The planning lifecycle strategies for these processes are described in the subsections below.

Capital investment drivers

Categories of capital investment generally have specific drivers or triggers that are derived from the state of the overall system or of individual assets. These drivers include demand growth, compliance with Grid reliability standards and failure risk (indicated by asset criticality and condition). Specific examples that drive capital investment in power cables include:

- new substation developments or expansions, driven by demand
- replacements for deteriorated or, in rare cases, failed assets, driven by asset condition and failure risk
- applications by property developers for undergrounding of overhead lines.

4.1.1 Enhancement and Development

The most important driver for new cables is the development of new transmission lines or substations. We have no inherent preference for either overhead or cable based developments and will seek to deliver the optimal solution on a case-by-case basis.

Overhead transmission line to cable conversion

Replace short sections of overhead lines with power cables.

In many areas around the Auckland, Tauranga and Christchurch regions residential/industrial estates have been built underneath existing transmission lines. The government has enacted the National Policy Statement on Electricity Transmission to restrict further 'underbuild'. The policy will require future residential or industrial development underneath our existing transmission lines to either deviate the existing transmission line or to convert it to underground power cables. The costs for the overhead transmission line undergrounding works will be fully funded by the applicant.[12]

Applicants for overhead transmission line undergrounding are typically property developers who are seeking to improve/maximise their property value. It is now economically viable for developers to underground a number of existing transmission lines, especially around the Auckland and Christchurch regions. It is expected that the number of transmission line to underground conversions, and so the number of critical cable circuits, will continue to increase over the next few years.

Before commencement we will need to be satisfied that such replacement proposals:[13]

- will not compromise security of supply, reliability and the capability of the network now or in the foreseeable future
- are technically feasible, fully compliant with current design specifications and achievable in terms of system outages and resources and within a timescale that does not adversely affect the network and wider investment programme
- are fully funded by the applicant, who will also be responsible for securing all agreements in principle to allow placement of all equipment on land and the acquisition of any necessary land without the need to resort to compulsory powers.

The following is a list of undergrounding projects we are currently committed to:

12 The costs of underground conversion projects do not form part of the RCP2 expenditure proposal, but it is important to discuss these undergrounding projects as they represent an increase in the number of assets, maintenance activities and affect performance of the power cable fleet.

13 Refer to "Undergrounding Transmission Lines in Urban Areas", April 2013 for detailed information regarding our current policy on this topic.

- 110 kV HAM – KPO A – St Kilda Development
- 66 kV KAI – SBK A – Silverstream Estates

It is difficult to anticipate the number of transmission line undergrounding projects during the RCP2 period as it is largely dependent on decisions beyond our control, and these projects are fully funded by the parties that require the undergrounding. We have received enquiries regarding the undergrounding of the following transmission lines:

- 220 kV HEN – OTA A, Penrose Container Terminal
- 220 kV HEN – OTA A, 110 kV PEN – ROS A and 110 kV MNG – ROS A, Onehunga (6 circuits in total)
- 220 kV OTA – WKM A & B, Flat Bush
- Various 220 kV and 110 kV transmission lines near the Hamilton Substation.

4.1.2 Replacement and Refurbishment

Replacement is expenditure to replace substantially all of an asset. Refurbishment is expenditure on an asset that creates a material extension to the end of life of the asset. It does not improve its attributes. This is distinct from maintenance work, which is carried out to ensure that an asset is able to perform its designated function for its normal life expectancy. In the case of power cables, replacement and refurbishment works are primarily triggered by poor asset condition and are undertaken to reduce failure risk. Specific interventions have been defined for cables based on their condition and informed by their relative criticality. These interventions and their rationale are set out below.

HV cable replacement at Bream Bay

Replace legacy HV power cables at Bream Bay substation.

The main load supplied from our Bream Bay substation is the New Zealand Oil Refinery at Marsden Point.

The refinery operations are critically dependent on a continuous supply of electricity. Even small interruptions of supply cause major disruption to the refinery, and significant losses. Information obtained from the refinery indicates that a loss of supply lasting more than a few days could lead to fuel supplies becoming depleted in the Auckland region (there is no bulk storage of fuel in Auckland, and supplies rely on continuous pumping through a pipeline from Marsden Point).

The Marsden Point refinery is a nationally significant load and, as a consequence, the main transmission circuits at Bream Bay have been assigned the highest level of criticality in our asset criticality framework.

The Bream Bay 220 kV oil-filled HV cables provide the only connection between the gas insulated switchgear in the substation and the power transformers that supply the customer load. There is no readily available means of bypassing the power cables or providing an alternative system of supply.

As outlined in subsection 2.2.3, defects have been found with the 28-year-old oil-filled 220 kV cables at Bream Bay. Repairs have been made, but there are concerns about the future reliability of these cables and the potential consequences of cable failure.

The risks and issues associated with cables at Bream Bay include those applying to the rest of the fleet of oil-filled HV cables as set out in section 2.3.4, including:

- difficulties, risks and costs of undertaking electrical tests of internal condition
- long lead time required for any major repairs
- specialist skills, spare parts and equipment required for any repairs.

While a major failure is a low probability event, the potential consequences could be severe. To manage the risk it is proposed to completely replace the Bream Bay 220 kV cables.

Technical issues that require consideration as part of this replacement include:

- the risk exposure while the cable replacement is undertaken
- coordination of maintenance with the refinery (which is typically short duration and infrequent)
- terminations for these cables at each end not complying with any current international standard – the GIS and transformer oil terminations are no longer easy to procure which presents a risk if new parts are required.

To manage the risk to the refinery while the cables are replaced, it is proposed to establish a temporary bypass that will provide an alternative source of 33 kV supply. This will involve the temporary use of one of our strategic spare 220/33 kV power transformers, and provision for a temporary or emergency connection to the 220 kV overhead line and the 33 kV switchgear.

The estimated cost for the cable replacement project includes an allowance for the costs of establishing this temporary bypass supply.

The total estimated cost for the replacement of the two cable circuits is $5.8m. This cost is based on desktop analysis of the site, recent cabling works and estimates from potential suppliers.

DTS systems replacement

Replace four DTS systems that are expected to reach end of life over the RCP2 period.

A number of 220 kV cables were installed as part of the NAaN, NIGUP and Otahuhu Diversity projects to reinforce the network supplying Auckland and Northland. These cables cost approximately $240m to install and are among the most critical cable circuits in our network. A fault/forced outage could have nationally significant economic consequences.

The NIGUP and NAaN cables were designed to support the projected load growth to 2030 and also to cater for a double contingent event where these cables will be the only supply available to Northland.

As mentioned in subsection 2.3.4, there are many unknowns associated with the thermal environment surrounding a cable circuit. Two DTS systems were installed with the NAaN cables and one with the NIGUP cables to provide better information about the cable thermal capabilities.

A further DTS system was provided with the 220 kV cables installed as part of the Otahuhu Diversity Project.

These systems allow us to monitor the temperature of the cables and provide us with an ability to understand their operation, validate the cable design and identify potential hot spots. We are currently investigating the application of DCR software to provide dynamic rating capabilities for these circuits.

The DTS technology and equipment is relatively new to us (the first system was installed in 2010), so we have not yet accumulated much data about life expectancy, condition or maintenance requirements. However, we anticipate that the DTS interface equipment will reach the end of its useful life and require replacement prior to the start of the RCP3 period.

The main business benefit of having a reliable DTS system in service is the confidence it provides in being able to operate the cables safely at high loads, particularly in contingency conditions, without causing significant risk to the cables or the network.

The estimated cost of replacement of all four units is approximately $1m based on the purchase cost for the NAaN project.

We do not anticipate installing new DTS systems for other HV cable assets.

New oil treatment equipment

Purchase oil treatment equipment to treat HV oil-filled cables during/after refurbishment of the cables.

Presently, there is only one mobile cable oil treatment plant in New Zealand that is considered suitable for use on our 220 kV oil-filled cables. This equipment belongs to an Auckland-based electricity distributor and we have used it to date on an opportunistic basis. Due to the critical nature of our 220 kV oil-filled cable circuits (see subsection 2.3.4 for more details), this is considered to be an operational risk as the equipment may not be available for our immediate use in the case of a cable fault or oil leak that requires the prompt deployment of the oil treatment plant.

As an alternative to continued reliance on borrowing this equipment on an opportunistic basis, we plan to purchase a new oil treatment unit during RCP2. The cost for a containerised unit is approximately $670,000.

4.1.3 Integrated Works Planning

Our capital governance process – IWP – includes the creation of business cases that track capital projects through three approval gates, with the scope and cost estimates becoming more accurate as the project becomes more refined. The specific strategies below describe how capital works on power cables will be optimised through the IWP process.

Power cable replacement/retirement during larger projects

Replace/retire power cables before they have reached their end of life if substantial projects are occurring at that substation.

As previously mentioned in chapter 2, we have a number of MV cables (including PILC cables) that are nearing their end of life in the RCP2 period. As part of the IWP process, many of these power cables will either be replaced or retired as an integral part of major substation works being undertaken during the RCP2 period. Examples of such works include:

- outdoor to indoor conversions

- indoor switchboard replacements
- power transformer replacements.

This integration of work drives lower overall risk to the system and supports our cost performance objective.

4.1.4 Cost Estimation

Cost estimation is a key stage of the capital investment process and forms a critical input into projects at various stages in the planning process. Historically, cost estimates for power cable capital works were developed using proprietary systems. This has now transitioned to a central cost estimation team, which uses the cost estimation tool Transpower Enterprise Estimation System (TEES). Further details on our cost estimation approach can be found in the Planning Lifecycle Strategy document.

Volumetric cable works are scoped to achieve P50

Develop primary scope descriptions for cable works so that cost estimates can be developed to achieve a P50 level of accuracy.

A key determinant of accurate cost estimates for capital projects is the scope of works and any factors likely to affect the cost of delivery. The main assumptions used for preparing cost estimates for power cable works include:

- accurate cabling routes
- geotechnical conditions
- material prices
- contractor resource availability
- project specific delivery requirements.

See the Planning Lifecycle Strategy for the rationale behind achieving P50 level of accuracy for volumetric cable work.

4.2 Delivery

Once the planning activities are completed, capex projects move into the Delivery Lifecycle. Delivery activities are described in detail in the Delivery Lifecycle Strategy. The following discussion focuses on delivery issues that are specific to the cable fleet.

4.2.1 Design

When applied to power cables assets, the design process aims to ensure safety, optimise the use of materials, standardise cable designs as much as possible, and ensure the cables are appropriately resilient to high loading events. In order for its standards to ensure the safety of personnel and the general public, we employ the 'safety by design' concept throughout the design process.

Minimise design diversity

Develop standardised designs and equipment for future cable installations.

Cable installation designs and equipment should be standardised in regard to:

- cable sizing for specific range of current rating
- cable termination or joint kits
- installation methods for cable termination
- development of a line/cable hybrid design.

Standardisation of cable types and sizing for power cables allows us to reduce the amount of spares required for contingency events and improve planning for procurement.

Standardisation of cable terminations and joint kits allows control over what type of termination and joint is installed for specific cable sizing and application. This will eliminate or minimise unapproved terminations or joints being installed on the network.

Standardisation of installation methods for cable terminations and joints allows consistent installation, and reduces the risk of deficient workmanship. The standardisation also enables consistent asset management, condition assessments, risk management, prompt/efficient fault response, repairs and improved/efficient cable jointer training.[14]

Alternative cable termination designs

Investigate cold applied, outer cone and inner cone termination design for connection onto transformer and switchgear.

Inner cone and outer cone terminations fully insulate all exposed energised terminals. The key benefit of such designs is to reduce the need for a fully enclosed cable box design for cable connection to new transformers or switchgear.

This will mitigate risks associated with confined space working, reducing the use of flame torches in confined spaces, and therefore reducing any fire risk.

Preventive maintenance such as testing is also easier without a fully enclosed cable box. A design that does not require enclosed cable boxes would also eliminate the risk of dry band,[15] which is caused by the high humidity that can occur in cable boxes.

4.2.2 Procurement

For more details of our general approach to procurement, see The Sourcing, Supply & Contracts Approach (2011) and the Delivery Lifecycle Strategy.

The subsection below provides more detail on the specific procurement strategies for power cable assets.

Economies of scale

Combine the procurement of similar cables across different projects to reduce overall cost of cable.

[14] Cable jointer training is important given that the task is now carried out by general network service providers rather than specialised cable jointers. This is highlighted in subsection 4.2.3.
[15] Appendix C includes further information about dry band on 33 kV cable terminations.

This strategy aims to reduce the overall cost of our cable procurement which is largely driven by commodity (such as copper) prices. The per-unit cost of power cable may vary with the length of cable being manufactured, as there is a set-up cost associated with manufacturing each run of cable. It will be beneficial for us to increase the average length of cable for each order by combining the procurement for similar cables from different projects. This has the effect of reducing the per-unit cost of the power cable. The cost saving must be weighed up against the cost of any additional storage, transportation, or other additional cost incurred by procuring cable ahead of requirement.

This strategy should also include procuring adequate contingency spares, including joints and terminations, to mitigate the impact of possible failures.

4.2.3 Construction

The construction phase of an asset's lifecycle is a large determinant of quality and has particular safety risks. This is why the project management of construction projects is important and is given substantial support and focus.

Improve quality of power cable joints/termination installations

Improve the quality of workmanship for future installation of MV cable joints/terminations.

We specify that all cable terminations and joints must be completed by either the cable accessory supplier or highly skilled and experienced cable jointers. This is supported by the training strategy for cable jointers discussed in section 4.6.

Over the past 10 years, 85% of our cable termination failures were caused by poor workmanship during the installation. We anticipate installing hundreds of cable terminations over the next 10 years. Good quality installation is one of the key factors in avoiding significant risks of equipment damage (to transformers or indoor switchgear) and interruptions to supply that can result from cable termination failures.

To reduce risks from deficient installation, we will maintain a lessons learned register for cable construction projects, which will be used to improve the quality of future projects. We will arrange for cable accessory suppliers to install MV cable terminations where feasible. We will also develop and provide a training and competency programme to train cable jointers installing cable terminations and joints (discussed in detail in subsection 4.6.3).

4.3 Operations

The Operations Lifecycle phase for asset management relates to planning and real-time functions. Our approach to operations is described in the Operations Lifecycle Strategy. The following discussion focuses on operational issues that are specific to the cable fleet.

4.3.1 Contingency Planning

The transmission network provides a critical infrastructure service for New Zealand. Failure of the transmission service leads to an immediate impact on end consumers and can result in large costs of disruption to economic and social activity. Some transmission asset failures can present serious safety hazards for employees and members of the public, or result in environmental damage. It is therefore essential that we have plans in place for responding effectively to cable outages.

Contingency response capability

Ensure there are sufficient plans, skilled manpower and emergency spares in place to enable rapid restoration of transmission service following failure or an emergency event such as an earthquake.

Resources must be sufficient to manage contingencies using a tiered response where local service providers rectify failures of small cables, and overseas specialists are available for failures of major cables. There is very limited availability of specialist personnel and specialist equipment in New Zealand and Australia.

We will develop and maintain a plan for repairs or replacement following failures of major cable circuits within two weeks if located within our substation boundaries and one month if outside them.

Temporary bypass arrangements

Consider temporary bypass arrangements to manage risk of extended outages for our most critical 220 kV cable circuits.

As previously mentioned in subsection 2.3.4, many of our HV cable circuits are of high criticality, especially the existing 220 kV cables at Bream Bay and Wilton substations and the new 220 kV NIGUP and NAaN cables. A cable failure or replacement or refurbishment of these critical 220 kV cables will result in these nationally significant loads being placed on 'N' security for a long time.

To manage these risks, a contingency plan may consider temporary bypass arrangements, where suitable, during the replacement, refurbishment or when a failure occurs on one of our critical HV cable circuits. A temporary bypass may involve temporary bays with associated switchgear, national spare transformers, transmission lines and protection.

A temporary bypass is already being considered for the 220 kV Bream Bay cable replacement planned in RCP2 (see subsection 4.1.2 for more details).

HV power cable spares holdings

Continually review and assess spares holdings for our HV power cable fleet.

As previously mentioned in subsection 2.3.4, our HV power cable fleet forms part of the most critical and essential transmission circuits in the country. We must have sufficient cable spares to manage the risk associated with extended outages if a cable failure occurs. We have acquired a large number of new 220 kV HV cable spares as part of the recent major capital upgrades such as the NIGUP, NAaN and Otahuhu Diversity projects. We also have a number of existing 220 kV oil-filled power cable spares that require further review and assessment as part of the detailed condition assessments planned in RCP2.[16] It is essential that we continually review and assess all of our HV spares holdings to ensure they are in adequate condition to be put in service when the need arises.

16 See subsection 4.4.1 for more information.

As part of routine condition assessments on our HV power cable fleet, we intend to review and assess the condition of the existing spares for each site being assessed. Depending on the results, we may acquire additional spares if the spares are found to be in deteriorating condition.

For new transmission line undergrounding or major cable replacement projects (such as the 220 kV Bream Bay oil-filled cable replacement), we will allow for new spares to be purchased as part of these projects.

4.4 Maintenance

We and our service providers carry out ongoing works to maintain assets in an appropriate condition and to ensure that they operate as required. The maintenance undertaken seeks to proactively manage failure risk as well as responding to actual failures as they occur. Our approach to maintenance and the activities we undertake are described in detail in the Maintenance Lifecycle Strategy. We class maintenance tasks into the following main categories:

- preventive maintenance
  - condition assessments
  - servicing
- corrective maintenance
  - fault response
  - repairs
- maintenance projects.

There will be a step increase in HV cable maintenance requirements as a consequence of commissioning more cable assets such as the large 220 kV cable projects in Auckland (NAaN & NIGUP) and the steady increase of overhead line undergrounding projects.[17]

The following discussion focuses on maintenance activities and associated strategies that are specific to the power cables fleet, including specific maintenance projects planned for RCP2.

4.4.1 Preventive Maintenance

Preventive maintenance is work undertaken on a scheduled basis to ensure the continued safety and integrity of assets and to compile condition information for subsequent analysis and planning. Preventive maintenance is generally our most regular asset intervention, so it is important in terms of providing feedback of information into the overall asset management system. Being the most common physical interaction with assets, it is also a potential source of safety incidents and human error. The main activities undertaken are listed below.

- **Inspections:** non-intrusive checks to confirm safety and integrity of assets, assess fitness for service, and identify follow up work.
- **Condition Assessments:** activities performed to monitor asset condition or predict the remaining life of the asset.

[17] The forecast maintenance cost is discussed further in the Maintenance Plan.

- **Servicing:** routine tasks performed on the asset to ensure asset condition is maintained at an acceptable level.

Regular cable patrols

Carry out regular cable route patrols on all cables installations, at the required frequency as determined by criticality, risk exposure, age and cable type.

Maintenance to avoid and identify external damage (predominantly due to unauthorised third party activity) or identify ground displacement (for cables with backfill) is the same for all cable types, with the most common practices being inspection of cable routes.

Cable patrols historically have been performed once a year on every cable asset because we have had a relatively small population of cable assets.

There has been a significant increase in cable maintenance requirements due to the recent commissioning of more cable assets, including the large 220 kV projects in Auckland (NAaN & NIGUP) and the undergrounding of overhead lines. Patrols are now undertaken weekly for the most critical HV cables.

Some cable circuits, especially direct buried cables, may require special route inspections after a significant storm event. This is due to the possibility of the storm washing out the surrounding backfill and exposing the cables.

MV power cable condition assessments

Carry out regular condition assessments on all cables installations, at the required frequency as determined by age and cable type.

This strategy is focused on assessing the condition of our MV cables assets to determine their overall health. MV cables are characterised by several factors, including age, voltage and insulation material. The maintenance requirements vary widely depending on these characteristics.

Our condition assessment programme monitors and records the condition of transmission assets and provides a basis upon which to investigate replacement or maintenance options.

As outlined in 2.2.4, diagnostic condition testing will be carried out on the MV and HV power cables, at varying intervals as determined by age and cable type.

MV power cable terminations condition assessment process improvements

Develop condition assessment processes, techniques and criteria to address the quality of MV cable installations.

We have over 200 cable circuits with heat shrink terminations that have suspected poor workmanship problems.

Replacement of the entire fleet of 33 kV heat shrink cable terminations is not the optimal approach to address ongoing reliability concerns given replacement of terminations for one cable circuit is estimated to cost approximately $150,000.

Condition assessment processes, techniques and criteria will be improved over the RCP2 period to identify specific 33 kV heat shrink terminations that should be considered for replacement. This may include applying methods such as PD and very low frequency testing as part of our standard maintenance procedures and recording the test results in the central data management system.

MV power cable partial discharge mapping pilot investigation

Undertake a pilot investigation into PD mapping of 33 kV cable circuits.

PD mapping is the assessment of cables for signs of a breakdown in the insulating properties of the insulation material that surround the conducting core. This can be caused by a crack in the insulation material or by moisture ingress. The results of the PD mapping enable more optimised maintenance and replacement of cables, often enabling minor repairs upon early detection rather than requiring major repairs or replacement once the situation worsens.

If this pilot investigation provides us with accurate and meaningful cable condition information, we will incorporate this technique into our standard maintenance procedures and start a programme of PD testing on the remaining power cable fleet.

HV oil-filled cable detailed condition assessments

Undertake detailed condition assessments on the 220 kV oil-filled cables located at Bream Bay, New Plymouth and Rangipo substations.

As outlined in subsection 2.2.3, the condition of our oil-filled cables at Bream Bay, New Plymouth and Rangipo need to be confirmed. Based on the installation date, cable construction, recent repairs and external condition assessments, it is expected that most are in deteriorating condition. We intend to undertake detailed condition assessments, which may include some oil tests, on these cables over RCP2 to determine if replacement/refurbishment is needed.

As mentioned in subsection 2.1.4, we have previously undertaken a review of our spare holdings as part of external condition assessments for these 220 kV oil-filled cable circuits. The condition of some of these spares is currently in question and the cable spares at New Plymouth substation have been scrapped due to not being stored properly. As part of these detailed condition assessment works, we will also undertake a review of our current spare holdings and assess whether we will acquire new cable spares or not.

We are currently testing the oil-filled cables at Wilton Substation in RCP1 as a pilot investigation. Any lessons learned from this test can be applied when we test the Bream Bay, New Plymouth and Rangipo oil-filled cables in RCP2.

4.4.2 Corrective Maintenance

Corrective maintenance includes unforeseen activities to restore an asset to service, make it safe or secure, prevent imminent failure and address defects. It includes the required follow-up action, even if this is scheduled some time after the initial need for action is identified. These jobs are identified as a result of a fault or in the course of preventive work such as inspections. Corrective works may be urgent and if not completed for a prolonged period may reduce network reliability.

Corrective maintenance has historically been categorised as repairs and fault (response) activities. Repairs include the correction of defects identified during preventive maintenance and other additional predictive works driven by known model type issues and investigations.[18] Timely repairs reduce the risk of failure, improve redundancy and remove system constraints by maximising the availability of assets. Activities include:

- **Fault restoration:** unscheduled work in response to repair a fault in equipment that has safety, environmental or operational implications, including urgent dispatch to collect more information.
- **Repairs:** unforeseen tasks necessary to repair damage, prevent failure or rapid degradation of equipment.
- **Reactive inspections:** patrols or inspections used to check for public safety risks or conditions not directly related to the fault in the event of failure.

Repairs

We will make repairs to power cable assets where a defect has been identified during preventive maintenance or fault response that could potentially result in a failure or when a failure has occurred. Over RCP2, we intend to implement the following repair strategies for the cable fleet.

Cable repairs

Ensure that sufficient, appropriate and competent resources and expertise are available to carry out major repairs to damaged and faulted cables.

Cable faults are extremely rare and unlikely events, but when they occur they can be very costly. On a single event basis, MV cable fault repairs are likely to cost between $50,000 and $200,000, while HV cable repairs would be in the vicinity of $100,000 and $1m.

Power cable repairs require specialised knowledge and equipment. Depending on the complexity of the cable construction, we may require overseas specialists to assist us.

In the event of a cable fault, the local maintenance service provider will isolate the faulty cable(s) and stabilise any adjacent network issues. They would then hand over all relevant information and safety measures to the cable repair service provider, who would then be responsible for returning the asset to service as quickly and efficiently as possible.

If a section of cable has been damaged beyond repair, the damaged section would have to be cut out and a new section inserted. Consequently, repairs may require two new joint bays with work continuing for several weeks.

The infrequent occurrence of these types of event means that it is not efficient to retain the skills and experience across the national range of station maintenance service providers. We may liaise with other asset owners of HV cable systems to establish NZ resource availability on an efficient scale. Yet there are few HV cables not owned by us in New Zealand. The optimal strategy is to select the most appropriate and competent service provider who can provide a nationwide response to a cable failure event.[19] In addition, we must keep in frequent contact to maintain effective relationships with overseas and local cable repair specialists.

[18] Where the number of potential repairs is deemed sufficiently high a Maintenance Project will be instigated to undertake the repairs works.

[19] For 220 kV cables, cable jointers would need to be brought to New Zealand from overseas.

Fault response

Fault response is required to restore the function of assets as quickly as possible to maintain supply to customers. This requires a specialised set of equipment, skills and experience to effectively locate, excavate and affect repairs. Typical issues faced when responding to a cable failure are noted below.

- Cable fault conditions (high impedance short circuit, low impedance short circuit, and open circuit, etc.) must be confirmed. This requires specialised test equipment and expertise interpreting results.
- The cable failure location needs to be identified and confirmed again with range of specialised test equipment, experience, expertise and local knowledge.
- Once the location of a repair is known, the cable repair needs to be planned and resourced, usually involving large numbers of stakeholders. Such planning can only be effectively undertaken by those with training and experience with managing HV cable repairs.

In light of the above issues, we intend to implement the following fault response strategies.

Testing vehicle

Develop partnership with an operator of a cable fault location test van.

Few cable faults are identical in nature. Often it is a combination of techniques and analysis of the results that help pin-point the location of a fault. The costs, delay and disruption to stakeholders of incorrectly locating the position of a fault often exceed the investment cost of a specialised test van in a single event. Such test vans are already in use for some lines companies in New Zealand.

We currently do not own any equipment for cable fault location and it may be cost effective for us to partner with one of the existing test van operators to include any additional equipment specific to our cable system requirements.

4.4.3 Maintenance Projects

As discussed in subsection 2.2.4, maintenance projects typically consist of relatively high value planned repairs or replacements of components of larger assets. Maintenance projects would not be expected to increase the original design life of the larger assets. Maintenance jobs are typically run as a project where there are operational and financial efficiencies from doing so. The drivers for maintenance projects include asset condition, mitigating safety and environmental risks, and to improve performance.

HV oil filled power cable repairs

Repair the legacy HV oil-filled power cables at New Plymouth, Rangipo and Wilton Substations.

There are four oil-filled cables in service at our Bream Bay, Wilton, New Plymouth and Rangipo substations.

Based on the installation date and the construction of the cables, it is expected that most are in a deteriorating condition and potentially in need of major repair (see subsection 2.2.3 for more details on asset condition).

To establish the degree of risk and the timing of required interventions, we will first carry out condition assessments on all of our oil-filled cables as outlined in subsection 4.4.1. Based on the outcome of the assessments at each site, major repairs including provision of real time pressure monitoring may be required.

For Bream Bay substation, we currently plan to undertake complete replacement, as outlined in subsection 4.1.2. For the cable installations at the remaining sites, major repairs are expected to be required to mitigate failure risk and potential loss of supply.

These major repairs are expected to cost approximately $0.5m for each site, which comes to a total of $1.5m over the RCP2 period. There is some uncertainty whether or not major cable repairs are required at the New Plymouth Substation due to the recent sale of the power station. We are currently investigating the possibility of reconfiguring the substation. We plan to reassess cable repair requirements once the site investigation is complete.

4.5 Disposal and Divestment

The disposal and divestment lifecycle phase includes the process from when planning of disposal of an asset begins through to the point where the asset is no longer owned by us.

Asset disposal includes the decommissioning of the asset after which it may be sold as a functioning asset, sold as scrap, disposed of to a waste management facility, or re-used elsewhere as an in-service asset or a spare. Asset divestment involves the sale of the in service asset as is and at its current location. Divestment often involves the sale of assets to customers, including electricity distribution businesses and large electricity users.

4.5.1 Disposals

Where re-use is not appropriate, we will maintain and follow appropriate decommissioning processes as part of projects. Successful disposal projects require effective site restoration.

Power cable disposal process

Where re-use is not appropriate, we shall maintain and follow an appropriate disposal process.

We will carry out an appropriate disposal process for any assets to be disposed, including safe work and site management processes and appropriate probity and environmental responsibility of scrap disposal processes. The disposal stage of the cable lifecycle will involve disposal of old oil-filled cables.

4.5.2 Divestments

While divestment involves a change of ownership, we must remain aware of any safety and environmental issues and technical impacts on the Grid that may arise, such as a change in constraints and flexibility of Grid operation.

Power cable divestments

Where appropriate, we shall look to reduce the amount of MV cable we own through divestment.

We are continuing with the transfer of a number of assets at the fringes of the existing Grid to distribution businesses. This process and its justification are described fully in the Disposal and Divestment Lifecycle Strategy.

It is important that we optimise our network boundaries with our connected customers (such as lines and generator companies) by divesting certain MV cables.[20] We will also ensure future power cable route designs take into account future divestments and address any asset boundary issues.

For the RCP2 period, we are planning to divest a 118m section of 110 kV cable on the Kensington to Maungatapere circuit together with its respective transmission line.

We are planning to divest a number of 11 kV and 33 kV power cables along with associated power transformers, indoor switchgear or outdoor 33 kV switchyard equipment.

4.6 Capability

We require our national Grid assets and equipment to be managed, maintained, tested and operated to high standards of skill, professionalism and safety. To achieve the required standards works must be carried out only by individuals with competencies that are both appropriate and current.

This section describes the approach used by us to ensure that these competencies are present in those undertaking work on the cable fleet.

The capability strategies are described under three headings:

- Risk Management
- Asset Knowledge
- Training and Competence.

4.6.1 Risk Management

Our approach to risk management is central to our asset management decision making as we weigh up the various costs and benefits of options such as replacement timing. We are developing asset health and criticality frameworks to improve and integrate our risk-based asset management. The strategies below discuss how we plan to progress this as regards the power cables fleet.

Non-invasive detailed condition assessment testing

Evaluate non-invasive detailed condition assessment testing to help develop an asset health model for power cables or as an indication for future power cable replacement.

As outlined in subsection 4.4.1, we are currently undertaking a pilot investigation of PD mapping of our MV power cable fleet. This is an initial step towards developing objective measures to be considered for asset health models or risk-based options evaluation for future cable replacements.

[20] The only MV cables we retain and operate are transformer ‘tails’/ ‘incomers’ or bus-tie/tie-line cable circuits.

We will continue to explore other options for testing, and detailed condition assessment that can be used in risk-based analysis.

4.6.2 Asset Knowledge

Robust and accessible asset knowledge is critical to good decision making for asset management. During RCP2 we will seek to improve our knowledge of our power cables fleet. An important part of this improvement will come from maintaining accurate records via standard maintenance procedures, which are discussed below.

Power cables asset knowledge

Improve the knowledge of power cables through accurate recording and updating of asset information.

Power cable asset knowledge is fundamental to robustly analyse faults, end-of-life predictions and replacement decisions. As mentioned in subsection 2.3.4, power cable asset knowledge is currently decentralised and there is a range of deficiencies. We have recently commissioned a new central database management system which will also be assisted by business improvements in data gathering, storage and retrieval processes. As part of this business improvement process, we are currently developing standard maintenance procedures to allow for more accurate recording and updating of asset information.

For power cables, we will further improve our asset knowledge by actively recording the following information into a centralised database:

- external condition assessments – this includes any corrosion, sheath damage, cable termination damage and oil leaks (from oil-filled power cables) along with photographic evidence
- records of maintenance fault repairs and electrical/oil test records
- records of in-situ soil thermal resistivity tests, dry-back tests, soil moisture content tests and DTS data in the asset management database
- records of the cable installation information such as the installer company, date of installation and photographic evidence of termination/joint installations (to improve our ability to identify any workmanship issues).

4.6.3 Training and Competence

Our overarching strategy for maintaining and/or improving worker competence is summarised below.

- All persons (our employees, service providers and service provider sub-contractors) working on our assets must be properly trained and currently competent for the tasks they undertake.
- All these workers must comply with the competency criteria set down in the relevant Service Specification.
- Employers must manage the currency of competencies of their workers for the work they undertake to the appropriate requirements of the relevant Service Specification.

We have two service specifications that define the competency requirements for working on transmission line assets.

- TP.SS 06.20 Minimum competencies for lines maintenance
- TP.SS 06.25 Minimum requirements for Transpower field work.

We maintain a minimum baseline of retained skilled workforce: engineers and site works operators who understand the physical assets.

Cable jointers

Develop a training and competency programme to train cable jointers installing cable terminations and joints.

We require service providers carrying out cable jointing to be certified, highly skilled cable jointers. Yet the market in New Zealand is too small to sustain specialised cable jointers; so it is inevitable that the work will be carried out by generalised service providers. We are involved in a number of industry initiatives to address training and related skill issues for MW service providers.

Service providers have a high staff turnover and the difficulties in retaining appropriate skills is exacerbated by the low level of demand for these services in New Zealand. This is also recognised as being a significant issue in Australia, where utilities also report problems securing suitably experienced and qualified cable jointers.

Proper training and mentoring should be provided to cable jointers working on our network to address the inconsistent and poor workmanship in the long term. This training will be developed with the assistance of cable accessory suppliers.

We now require cable jointers to hold certification given by manufacturer that they are deemed competent to install terminations.

We aim is to eventually have manufacturers carry out the terminations to ensure correct level of expertise.

The increasing amount of HV cables in our network may require further investment in awareness and competency training to highlight the hazards associated with being in close vicinity to these cables.

4.7 Summary of RCP2 fleet strategies

Our strategies for the fleet of power cables are summarised below for each lifecycle stage.

Planning	
Enhancement and Development	Replace short sections of overhead lines with power cables.
Replacement and Refurbishment	Replace legacy HV power cables at Bream Bay substation.
	Replace four DTS systems that are expected to reach end of life over the RCP2 period.
	Purchase oil treatment equipment to treat HV oil-filled cables during/after refurbishment of the cables.
Integrated Works Planning	Replace/retire power cables before they have reached their end of life if substantial projects are occurring at that substation.
Cost Estimation	Develop primary scope descriptions for cable works so that cost estimates can be developed to achieve a P50 level of accuracy.

Delivery	
Design	Develop standardised designs and equipment for future cable installations.
	Investigate cold applied, outer cone and inner cone termination design for connection onto transformer and switchgear.
Procurement	Combine the procurement of similar cables across different projects to reduce overall cost of cable.
Construction	Improve the quality of workmanship for future installation of MV cable joints/terminations.
Operation	
Contingency Planning	Ensure there are sufficient plans, skilled manpower and emergency spares in place to enable rapid restoration of transmission service following failure or an emergency event such as an earthquake.
	Consider temporary bypass arrangements to manage risk of extended outages for our most critical 220 kV cable circuits.
	Continually review and assess spares holdings for our HV power cable fleet.
Maintenance	
Preventive Maintenance	Carry out regular cable route patrols on all cables installations, at the required frequency as determined by criticality, risk exposure, age and cable type.
	Carry out regular condition assessments on all cables installations, at the required frequency as determined by age and cable type.
	Develop condition assessment processes, techniques and criteria to address the quality of MV cable installations.
	Undertake a pilot investigation into PD mapping of 33 kV cable circuits.
	Undertake detailed condition assessments on the 220 kV oil-filled cables located at Bream Bay, New Plymouth and Rangipo substations.
Corrective Maintenance	Ensure that sufficient, appropriate and competent resources and expertise are available to carry out major repairs to damaged and faulted cables.
	Develop partnership with an operator of a cable fault location test van.
Maintenance Projects	Repair the legacy HV oil-filled power cables at New Plymouth, Rangipo and Wilton Substations.
Disposal and Divestment	
Asset Disposals	Where re-use is not appropriate, we shall maintain and follow an appropriate disposal process.
Divestments	Where appropriate, we shall look to reduce the amount of MV cable we own through divestment.
Capability	
Risk Management	Evaluate non-invasive detailed condition assessment testing to help develop an asset health model for power cables or as an indication for future power cable replacement.
Asset Knowledge	Improve the knowledge of power cables through accurate recording and updating of asset information.
Training and Competence	Develop a training and competency programme to train cable jointers installing cable terminations and joints.

Appendices

A CABLE TERMINATION TYPES

IXSU/OXSU cable terminations

IXSU/OXSU is a one-piece heat shrink termination design that incorporates the stress control layer and polymer sealant in one tube. The stress control layer is extruded on the inside of the polymer sealant tubing.

At 33 kV, a silicon carbide void filling mastic is used to provide higher technical margins during the qualification testing to comply with international standards such as IEEE, VDE and CENELEC.

Due to this design, sufficient uniform heating is required during installation of the termination, to allow heat to transfer onto the stress control layer and void filling mastics, and ensure a void free installation.

Install period: 2001 to 2011.

EPKT and HVTI/HVTO cable terminations

The EPKT design consists of a separate stress control tube and a polymer sealant tube. The stress control tube is first shrunk down to the cable insulation, before shrinking the polymer sealant tube over the cable. Furthermore, EPKT design uses a yellow void filling mastic instead of the silicon carbide void filling mastic that required less heat to amalgamate onto the screen cut area.

This two-part design along with lower temperature mastic allows better heating processes to amalgamate the void filling mastic onto the screen cut area and the stress control tube onto the cable insulation.

HVTI/HVTO is the modern equivalent replacing the EPKT type cable terminations.

EPKT Install Period: 1980s to early 2000.

HVTI/HVTO Install Period: ongoing since 2011.

Traditional insulator-style cable terminations

Outdoor sealing ends are cable terminations that interface with air-insulated equipment and are normally subjected to full climatic conditions. At 11 kV to 33 kV, only paper insulated cables have these type of terminations installed. Examples of this termination type installed in Transpower are the North Makarewa T1 and T2 33 kV paper insulated cable (see Figure 5).

Figure 5: 33 kV North Makarewa cable terminations for paper insulation cables

Cold shrink and cold applied cable terminations

Cold shrink terminations are a moulded elastomeric sleeve. The sleeves usually contain a resistive or high permittivity filler to control the longitudinal stress distribution. Transpower has installed cold shrink termination at Whirinaki and various 11 kV LMVP-type switchboards (see Figure 6).

Install period: Ongoing since 2010.

Figure 6: OTK type 11 kV outdoor cold shrink termination used at Whirinaki

There are two key types of installation systems, including a pre-expanded removable tube or a push-on/slip-on type system. For the pre-expanded removable tube installation system (see Figure 7), once the removable tube is fitted over the prepared cable, the tubing is removed. The termination body then shrinks down onto the prepared cable insulation.

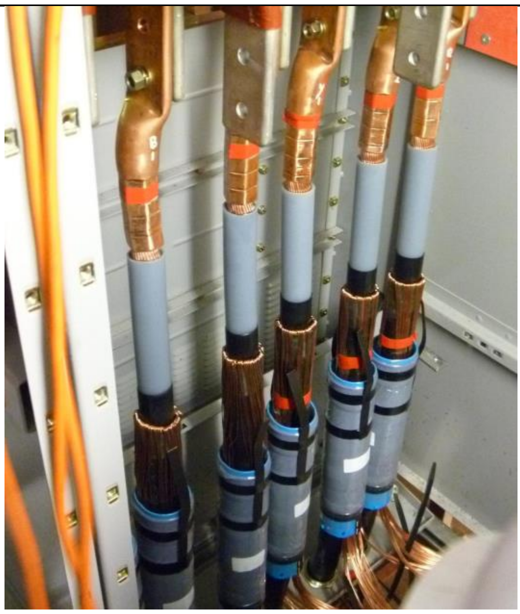

Figure 7: Removable tube-type cold shrink termination

Cable Termination within a compound filled cable box (legacy installations only)

The cable is terminated inside a compound filled cable box (pitch, penetrol, or Guroflex silicon-type compound). The purpose of the compound is to provide sufficient insulation for the tight clearances within the cable box (such as the Motunui T3 Transformer cable box shown in Figure 8).

Figure 8: Motunui T3 Transformer Penetrol Filled Cable Box (Now Filled with Guroflex)

Inner cone cable terminations

The inner cone plug is a type of separable connector that is a fully insulated termination permitting the connection and disconnection of a cable to a switchgear or transformer. Transpower primarily uses Pfisterer inner cone plugs for cable terminations on Areva GHA and WSA indoor 33 kV switchboards (see Figure 9).

Install period: Ongoing since 2002.

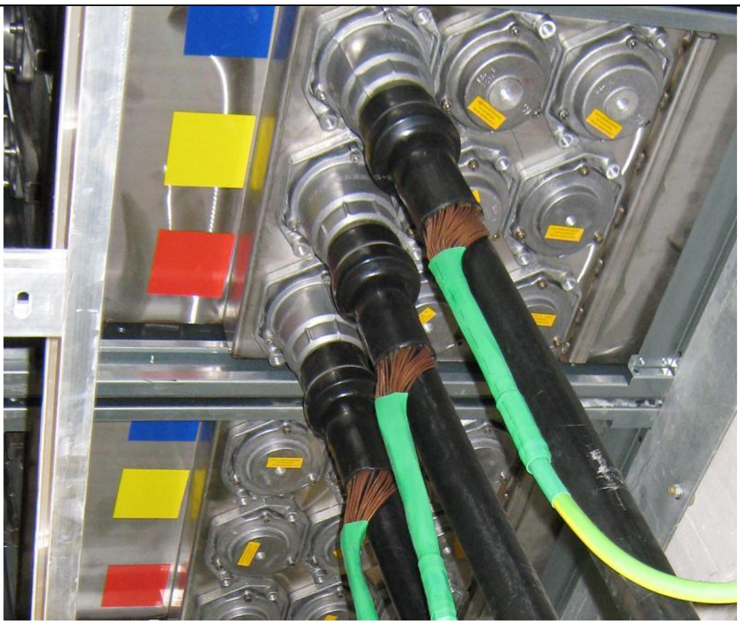

Figure 9: Pfisterer Plugs Installed into the GHA/WSA Switchboard

Gas insulated sealing end

Gas insulated sealing ends (GISE) are cable terminations connected to a busbar within a metal trunking insulated with a gas usually pressurised SF_6 gas (see Figure 10). This cable termination type is mostly installed on cables above 66 kV.

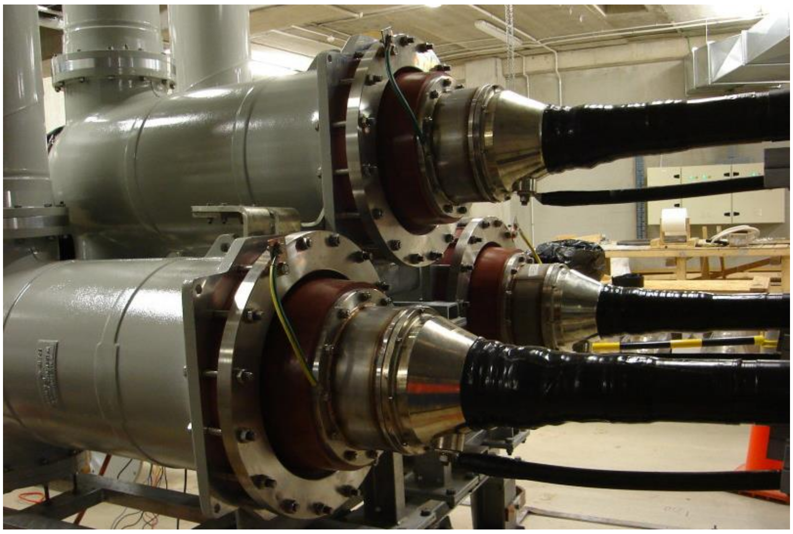

Figure 10: OTA OHW CCT2 sealing end under pre-commissioning testing

Outdoor sealing end

Outdoor sealing ends (ODSE) are cable terminations that interface with air-insulated equipment and are normally subjected to full climatic conditions (see Figure 11).

Figure 11: 220 kV OTA HEN CCT1 – 2500 mm^2 cable

Oil immersed sealing end

Oil immersed sealing ends (OISE) are cable terminations connected to a busbar within a metal trunking insulated with oil. This cable termination type is normally installed inside a transformer housing (cable box) for power cables above 66 kV (see Figure 12).

Figure 12: 220 kV OISE BRB-CBL-112

B PHOTO OF CABLE TERMINATION SAFETY RISKS

Fire risk in confined space when installing cable terminations

Figure 13: Cable jointers using a flame torch inside a cable box to install heat shrink termination

C ISSUES WITH 33 KV HEAT SHRINK TERMINATIONS

Failures due to poor installation workmanship

We experienced the first known IXSU/OXSU failure at Stoke in 2005 inside a 33 kV Schneider indoor switchgear panel (see Figure 14). From examination of the failed termination, the root cause of failure is most likely to be poor workmanship, where insufficient heating was applied to the 33 kV IXSU/OXSU heat shrink cable termination.

The failed cable termination was cut, a repair joint was installed using spare cable and a new termination was fitted. The other cable terminations were re-heated to ensure stress control material amalgamated to the cable insulation.

A second cable termination failure occurred in 2008 inside the same cable box (see Figure 15). Once again, failure investigation showed that the cable termination failures were caused by poor workmanship at the screen cuts, and insufficient heating applied to the cable termination. Re-application of heat on these cable terminations in 2005 had not helped the situation.

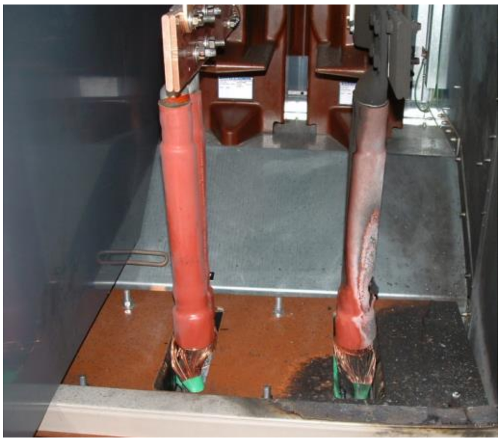

Figure 14: First failure at Stoke in 2005

Figure 15: Second failure at Stoke in 2008

Since the first 33 kV IXSU/OXSU failure:

- our contractors have continued to install the 33 kV IXSU/OXSU cable terminations into Transpower network with new supply transformer and switchgear installation projects
- to date, Transpower has installed over 800, 33 kV IXSU/OXSU cable terminations of the type that has had systemic problems
- the contractor cable jointers' skill levels do not appear to have improved since the 2005 failure
- we stopped using 33 kV IXSU/OXSU cable terminations in September 2011.

We have continued to experience a number of failures with this type of termination, which shows that this root cause failure was never resolved after the first failure.

Table 12 shows the number of cable termination failures associated with 33 kV IXSU/OXSU cable terminations of the type with model-wide problems. Mean time to failure is approximate two years after installation.

Device Position	Date of Fault	Fault Location	Voltage (kV)	Cable Type	Installed Year	Years Before Failure
STK-CBL-2248-427	December 2005	CB Coupler	33	XLPE	March 2005	0.8
STK-CBL-2248-427	November 2008	CB Coupler	33	XLPE	December 2005	2.9
BAL-CBL-T2/282	April 2009	T2 outdoor	33	XLPE	October 2005	3.5
PRM-CBL-T4-LS4	January 2011	LST Cable box	33	XLPE	September 2009	1.4
WPW-CBL-T33-33	April 2011	T33 Cable box	33	XLPE	September 2008	2.6
INV-CBL-T5	September 2011	T5 Cable box	33	XLPE	April 2008	3.4
PRM-CBL-T3	November 2011	T3 Outdoor	33	XLPE	September 2009	2.2

Table 12: 33 kV IXSU/OXSU Cable Termination Failures

The following service advisories have been put in place to address these issues.

- TP.SS 02.46 SA2 – 'Inspection & Replacement of 33 kV Heat Shrink Termination' service advisory was released in September 2011 to inspect all 33 kV cable terminations identified to be IXSU/OXSU type. This inspection survey is in progress and is planned to be completed by end of 2013. As a part of this service advisory, Transpower has advised our project contractors to stop all use of 33 kV OXSU/IXSU types with systemic problems for future installations.
- TP.SS 02.46 SA3 – 'Power Cable Jointing and Termination Work Documentation' service advisory was released in July 2011, to require all cable jointers installing joints and termination to complete a work record form, take photographs during the installations, install nameplates, and input information into our maintenance management system.

Dry-band formation inside transformer cable box

This is another example of poor installation of the 33 kV heat shrink terminations. A severe case of dry-band formation on the cable terminations was found at Mount Maunganui during the inspection survey on our fleet of 33 kV heat shrink terminations. These cable terminations were installed inside a ventilated transformer cable box.

High humidity within a cable box can cause moisture build-up on the surface of the termination. When the surface of an energised termination is covered with a conducting pollution layer such as moisture, surface leakage current will flow that leads to dry-band formation in the regions of high current density and low wetting.

Figure 16 shows the dry-band formation near the removed insulation screen area where the longitudinal stress is concentrated when the termination's stress control is not functioning as originally designed. **Note:** This termination was deemed to have been poorly installed, causing the termination's stress control layer to malfunction.

Figure 16: The white filler on the termination reacts to minimise the rate of erosion due to dry-banding

D HV POWER CABLE SPARES

For recent HV power cable installations, manufacturer spares have been procured as part of the project. Further details are provided in Table 13.

Project Name	Cable Spare	Joint Spares (No.)	Termination Spares (No.)	Other Spares
Otahuhu Diversity Project, 220 kV	315m x 1200mm^2 Cu XLPE 95m x 2500mm^2 Cu XLPE	2 x Straight through joints	4 x Outdoor terminations 2 x GIS terminations	3 x Sheath Voltage Limiters (SVL) 1 x Cable Neutral Current Transformer
NIGUP, 220 kV	600m	8 x Straight through joints	2 x Outdoor termination	2 x Cross bonding link boxes (with and without SVLs) 2 x Solid/Mid-point link boxes (with and without SVLs) 1 set of termination standoff Insulator 1 set of specialist tools
PAK – PEN, 220 kV	310m	2 x Straight through joints	1 x Outdoor sealing end	
PEN – HOB, 220 kV	300m	2 x Straight through joints	1 x GIS sealing end	
HOB – WRD, 220 kV	1345m	2 x Transition joints (1600mm^2 to 2500mm^2) 2 x Straight through joints	2 x GIS terminations	
WRD-ALB, 220 kV	600m	2 x Cross bonding joints	1 x Outdoor terminations	
ALB-HEN A & B, 110 kV	100m	2 x Straight through joints	1 x Outdoor termination	1 set of termination standoff insulator 1 x Link box 1 set of specialist tools
Highbrook, 110 kV	500m x 1000mm^2 Cu XLPE 500m x 400mm^2 Cu XLPE	2 x Straight through joints for 1000mm^2 Cable 2 x Straight through joints for 400mm^2 Cable	1 x Outdoor sealing end including porcelain bushing 1000mm^2 1 x Outdoor sealing end including porcelain bushing 400mm^2	1 x Cross bonding link box 1 x Direct earth link box 1 x Structure mount direct earth link box

Table 13: New HV XLPE power cable spares