Insulated Cable Systems

AMS – Electricity Distribution Network

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Table of Contents

1 Executive Summary

This document is part of the suite of Asset Management Strategies relating to AusNet Services' electricity distribution network.

The purpose of this strategy is to explore issues and define the company's approach to the management of insulated cable systems. These consists of high voltage, medium voltage and low voltage insulated underground cables and medium voltage and low voltage insulated overhead cables including covered conductor systems.

There is over 6,700 km of underground and overhead insulated cables in the eastern part of Victoria. The insulated cable population has been steadily growing at approximately 3% per annum.

Underground insulated cable systems have been in service since the 1970's and overhead insulated cable systems were introduced in the 1990's. These populations have significantly increased over the past two decades, attributed to requirements of housing in underground residential development (URD) estates using medium voltage and low voltage underground cables.

Overhead medium voltage insulated cables systems are in the poorest condition and are exhibiting high failure rates suggesting end-of-life when compared to underground insulated cable systems. The replacement program continues to see these high risk cables being replaced with either a more robust design of overhead cable or by underground cable.

Although underground insulated cable systems are exhibiting low failure rates, objective health information of the cable system is required to ensure prudent future economic replacement programs are developed. Condition monitoring programs have been developed and will continue to be rolled out during this EDPR period.

Proactive management of insulated cable application, inspection, maintenance, refurbishment and replacement practice is required to ensure that stakeholder expectations of cost, safety, reliability and environmental performance are met. This incorporates but is not limited to the Hybrid network which reduces cost by utilising existing infrastructure and providing an underground solution.

1.1 Asset Strategies

The following strategies shall be used to manage risks associated with insulated cables, both overhead and underground.

1.1.1 New Assets

- Where practical, the vast majority of new installations will use underground cable circuits, rather than ABC configurations.
- As the cable network continues to be renewed because of either in-service failures, condition assessment results, high condition score or REFCL testing outcomes, the population of PILC cables will diminish until eventually they will no longer exist on the network.
- All new cable systems shall be commission tested to the protocols detailed in SMI 12-01-02
- In order to minimise the effect of poor installations and to ensure the maximum cable circuit reliability, the following measures have been or are being implemented
  - Using only accredited installers, trained by the specific accessory manufacturers
  - Where practical, designing (and repairing) of all cable circuits to have no joints

1.1.2 Inspection

Non-invasive inspection and testing methodologies can be utilised on in-service assets to determine the presence of outward signs of a deteriorated inward condition. Simple things like an oil leak on a HV cable termination can lead to a catastrophic failure if left unchecked.

1.1.3 Maintenance

The following maintenance activities will continue to be refined

- Recording of fault codes to enable disaggregation of failure modes by cable or accessory type
- Fault data collection for each cable failure to determine root cause of the failure and enable trending
- Recording of installers/jointer details to improve efficiencies

Maintenance strategies of insulated cables are voltage and environment dependant

LV cables

- Both overhead and underground, will continue to be replaced on condition as determined by the criteria in Table 1, or earlier if they fail in service or are replaced during network upgrade works

MV underground cables will continue to be maintained in the following traditional manner

- Critical cables, as defined in the testing Standard Maintenance Instruction (SMI), within stations shall have no joints. Temporary joints may be permitted for a period of no greater than six months to enable supply to be restored
- Following an in-service failure of cable and/or in-line joint, the failed portion shall be cut out and replaced with two joints and a short length of new cable
- A HV customer supply cable that has a circuit length less than 100m shall be replaced rather than repaired
- Termination failure, where enough spare length cannot be recovered from the cable, will have a new inline joint installed within 4 metres of the base of the pole and a new tail length of cable installed and terminated
- MV PILC cable failures, and possible subsequent testing, will preferably cause the entire cable circuit to be replaced. If this is uneconomical then the repair shall be covered by the above two XLPE methodologies except that the joints to be used will be transition/sealing joints to ensure that the paper/oil system is sealed.
- HV Oil Filled Cable (OFC) failures will again preferably cause the entire cable circuit to be replaced. If this is uneconomical then the repair shall be covered by the above two XLPE methodologies except that the joints to be used will be stop joints to ensure that the paper/oil system is sealed and pressurised.

1.1.4 Obsolescence and Spares Management

- Due to the large volume turnover of LV and MV insulated cables, the strategic spare holding levels for such cables is minimal. There is always stock within the stores systems that can be used to respond to failures
- There are some MV underground cable circuits that have a slightly different design than those typically used. These design differences usually dictate that a strategic spare be on hand should a failure occur.
    - Two examples that might help understanding are larger screen wire cross section to carry higher fault ratings in a particular installation or a special outer protective sheath construction. For such cables at least one drum of strategic spare cable would be deemed necessary in order to facilitate the correct repair.
- HV cable circuits are typically bespoke designs for particular applications and as such would dictate the carrying of strategic spares of both cable and possibly accessories. The number of spare joints, if required, shall be sufficient to facilitate the repair of the three phase circuit.
- While HV Oil Filled Cables exist on the network, strategic spare transition and stop joints are required. Again, the preference is to replace these cable circuits, however due to long circuit lengths such replacements may not be economically viable. In such cases the required number of joints shall be sufficient to facilitate the repair of the three phase circuit without the need to have to replace the entire cable.

1.1.5 Refurbishment

Replacement, rather than refurbishment, is the only viable option in regards to LV, MV and HV cable systems.

1.1.6 Replacement

Continue replacement of MV Overhead 22kV NMS ABC with LDMS. Planned to be completed by the end of 2021. Replacement of a section of the BRT21 feeder to Mt Hotham has been allowed for in this submission.

1.1.7 Research and development

Explore economics of alternative overhead covered conductor solutions

2 Introduction

2.1 Purpose

The purpose of this document is to outline the inspection, maintenance, replacement and monitoring activities identified for economic life cycle management of insulated cable assets. This document is intended to be used to inform asset management decisions and communicate the basis for activities.

In addition, this document forms part of our Asset Management System for compliance with relevant standards and regulatory requirements. It is intended to demonstrate responsible asset management practices by outlining economically justified outcomes.

2.2 Scope

The assets covered by this strategy include insulated cables designed for both overhead and underground installation, divided into the following internationally recognised voltage categories, and simplified for the company's networks

High Voltage (HV)	: 66kV	
Medium Voltage (MV)	: greater than 1kV and less than 36kV	or expressed as 1kV < MV < 36kV
and Low Voltage (LV)	: greater than 32V and less than 1kV	or expressed as 32V < LV < 1kV

The following assets are not covered by this strategy:

- Cables to be replaced as part of REFCL resilience test requirements – refer document REF 20-10

The Company has recently transitioned to a new SAP Asset Management database system. This transition has revealed many deficiencies with underground cable asset data that are systematically being corrected. The data presented in this strategy is taken from the best data capture that can be made at this point in time.

2.3 Asset Management Objectives

As stated in *AMS 01-01 Asset Management System Overview*, the high-level asset management objectives are:

- Comply with legal and contractual obligations;
- Maintain safety;
- Be future ready;
- Maintain network performance at the lowest sustainable cost; and
- Meet customer needs.

As stated in *AMS 20-01 Electricity Distribution Network Asset Management Strategy*, the electricity distribution network objectives are:

- Improve efficiency of network investments;
- Maintain long-term network reliability;
- Implement REFCL's within prescribed timeframes;
- Reduce risks in highest bushfire risk areas;
- Achieve top quartile operational efficiency; and
- Prepare for changing network usage.

3 Asset Description

3.1 Asset Function

Insulated cable systems, both overhead and underground, form an integrated portion of the AusNet Services electricity distribution network. Insulated cables are used to transport High Voltage (HV), Medium Voltage (MV) and Low Voltage (LV) electrical power through different parts of the network where safety, environmental or physical space limitations dictate that they be used instead of bare overhead conductors. Insulated cables are typically immune to the effects of bushfire, flood or similar natural incidents that would normally have adverse effects on their bare overhead counterparts.

Insulated cables are used throughout the AusNet Services electricity distribution network to:

- Interconnect zone substations
- Interconnect primary assets within a zone substation
- Interconnect indoor switchgear to the remainder of the zone substation
- Form the back-bone of feeder circuits out from a zone substation
- Form sections of circuits that travel through different terrain that might dictate the use of insulated cables
- Supply power to and throughout new industrial and housing estates

3.2 Asset Population and Age Profile

3.2.1 MV Overhead Cables

The electricity distribution network contains three design types of MV overhead insulated cable; non-metallic screened high voltage aerial bundled cable (NMS HV ABC), light duty metallic screened high voltage aerial bundled cable (LDMS HV ABC) and insulated unscreened conductor (IUC), which includes spacer cable systems (SCS) such as Hendrix spacer cable systems, shown in Figure 1. Each of these designs use cross-linked polyethylene (XLPE) as the main insulation.

HV ABC utilise fully insulated cables whereas IUC systems, such as Hendrix cables are classed as using covered conductors, rather than insulated conductors.

Figure 1 – Typical Hendrix Cable System

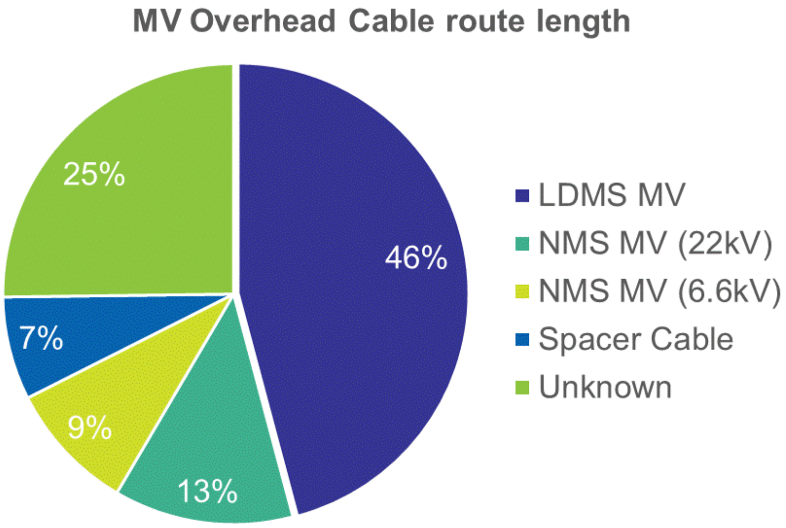


Figure 2 illustrates the population distribution for MV insulated cables currently in service as percentage of cable type out of the total length of MV OH cable. The NMS HV ABC[1] was first installed in the Dandenong Ranges to the east of metropolitan Melbourne in 1988. This type of cable was introduced in response to high outage rates of the open wire systems from tree-bark faults[2] and was utilised in heavily timbered routes or during the reconstruction of problematic open-wire lines. However there is a fundamental design problem with this cable as discussed in section 3.3.1 which instigated a replacement program. To date the program has, along with the installation of new LDMS circuits, reduced the NMS cable from more than 50% to only 13% of the MV overhead cable population. The program will continue to replace all critical NMS cables over this EDPR period.

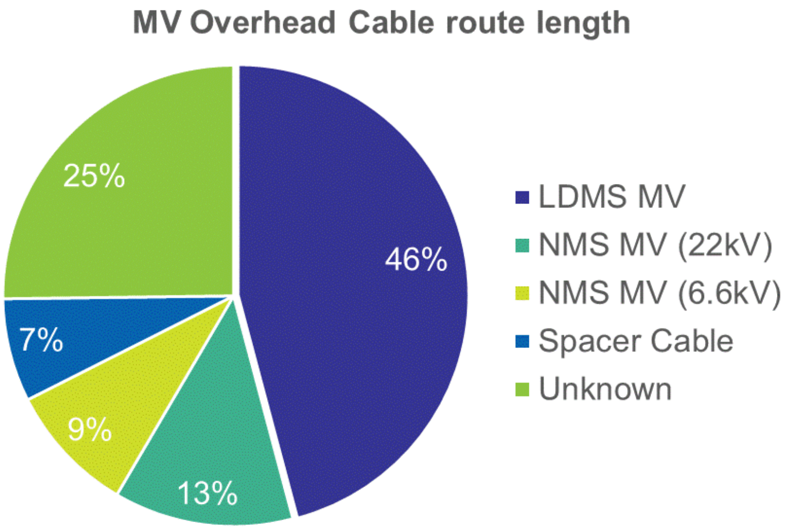


Figure 2 – MV Overhead Insulated Cable Population Summary by cable type

LDMS HV ABC and HV IUC (Hendrix) systems were adopted after 2010.

Figure 3, below is a Google Earth extract of AusNet Services' distribution network. Represented against Victoria, the bare overhead distribution network, shown in orange covers the eastern part of the state. Highlighted in green is the installed MV ABC network, predominantly used in the Mt Dandenong region.

[1] Development and introduction of aerial bundled cables in Australia – Williamson, C. E. et al, 1988.

[2] Authority to proceed - HV & LV ABC in area of particular significance 92/93, SECV, 19 November 1992.

As a consequence of being applied in highly vegetated locations, HV ABC operates in high bushfire risk areas. These circuits are exposed to high environmental effects and severe consequences of failure.

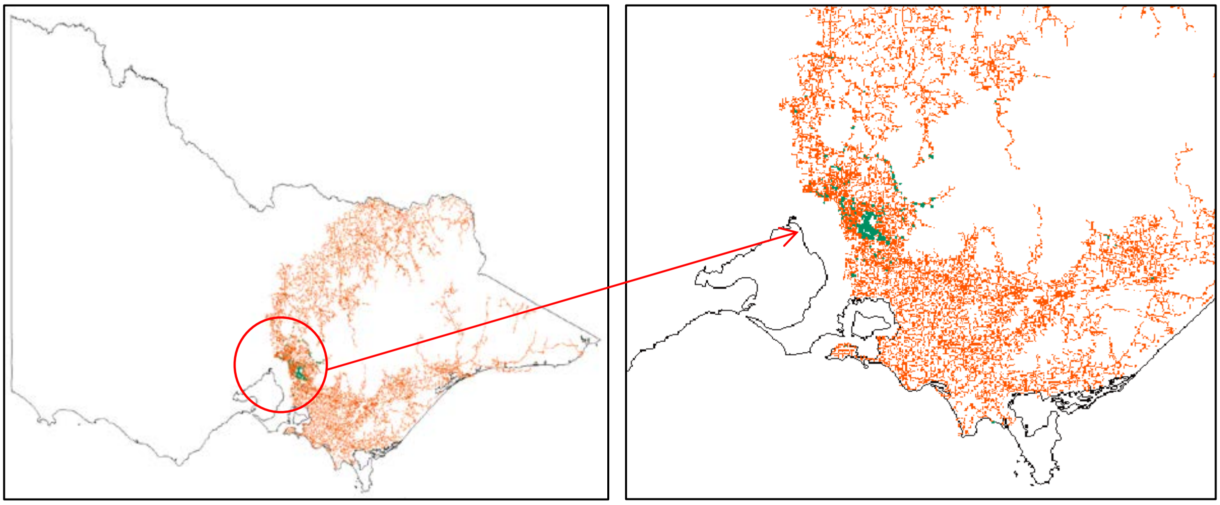


Figure 3 –AusNet Services' distribution network (MV ABC in green).

Figure 4 illustrates insulated cable systems that have been installed in heavily treed environments to reduce vegetation management and improve fire ignition safety.

Figure 4 – MV Overhead Insulated Cables (Dandenong Ranges, Victoria)

Figure 5 shows the extent of insulated cable systems installed in the Mt Dandenong Ranges to reduce the risk of fire ignition as a consequence of trees or stringy bark contacting a bare overhead line.

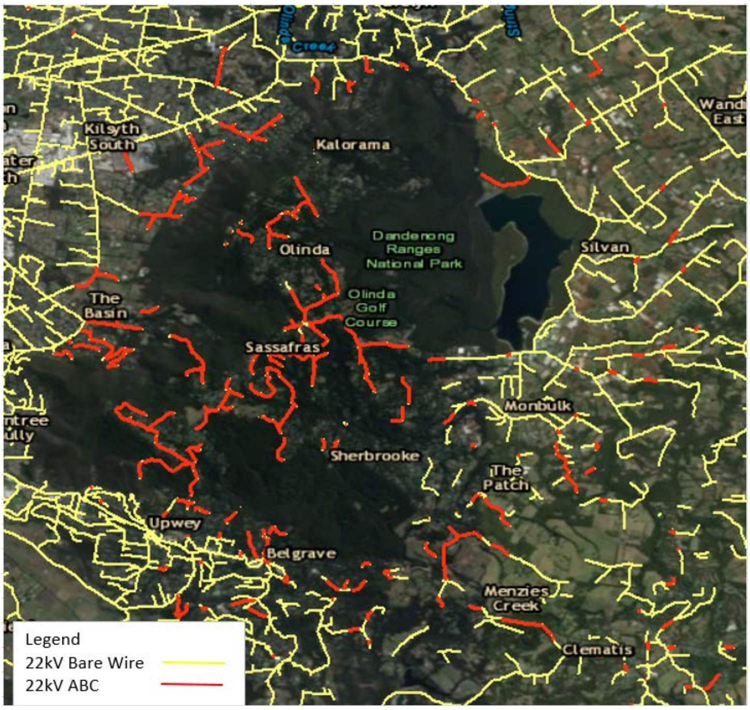


Figure 5 – Google Earth extract of Bare Wire and HVABC lines in the Dandenong's

Figure 6 illustrates the age profile of MV- OH cables age profile as percentage of total MV OH route length.

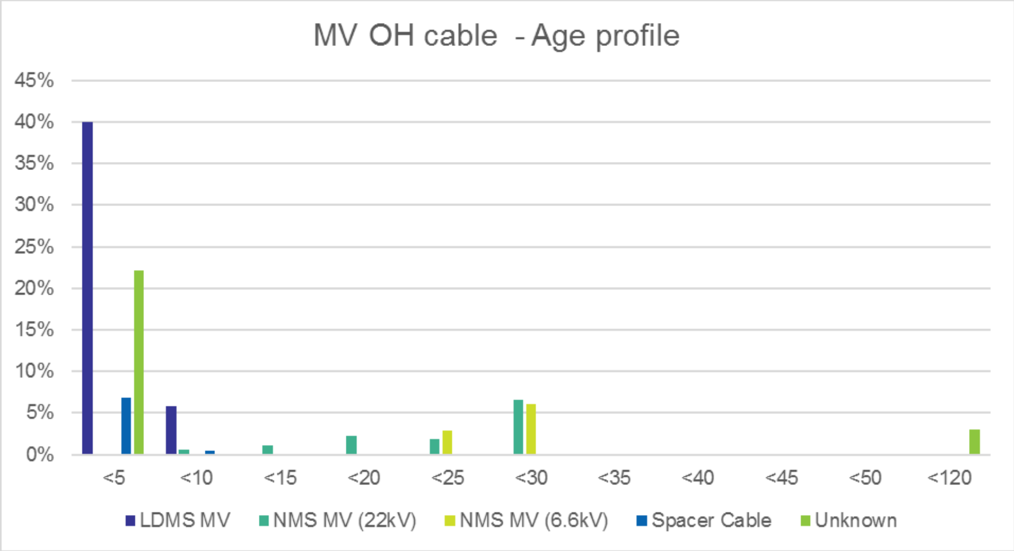


Figure 6 - MV OH cable Age Profile

3.2.2 LV Overhead Cables

The majority of the low voltage electricity reticulation network cables are XLPE insulated having aluminium conductor cross sections ranging from 25 mm^2 to 185 mm^2. Figure 7 illustrates the percentage of each LV OH ABC cable type out of the total length of LV ABC cables.

These cables were introduced in the 1980s, with the majority of the installations in the 1990s. These cable systems were used for all new circuits across the eastern part of Victoria except when underground cables were used to supply URD housing estates.

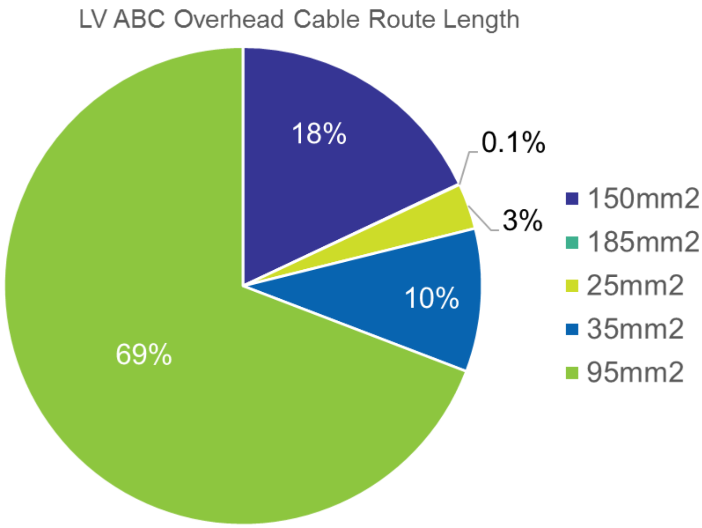


Figure 7 – LV Overhead Cable Population Summary

Figure 8 illustrates the age profile of LV- ABC OH cables as percentage of total LV-ABC OH route length.

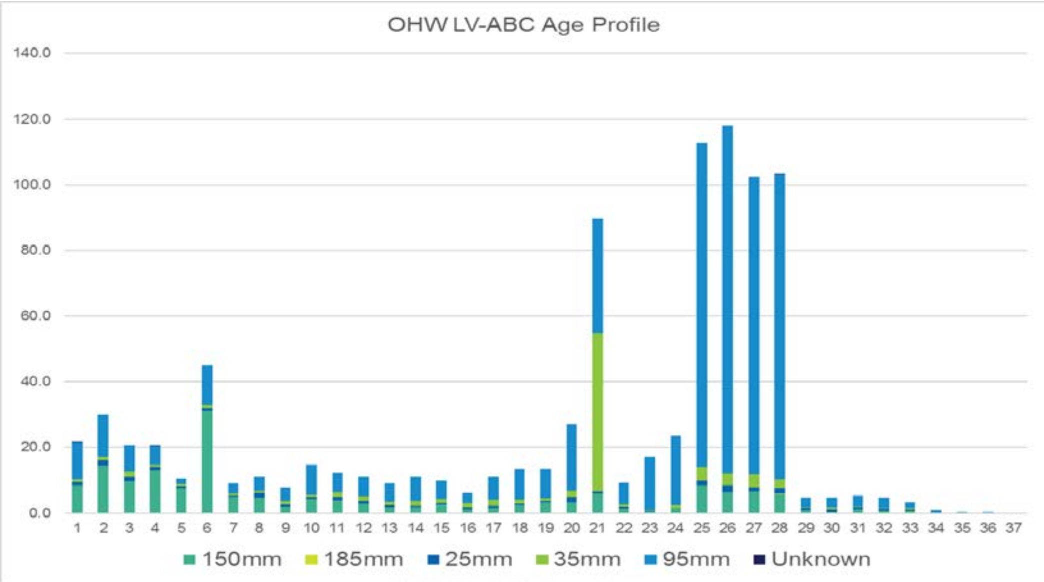


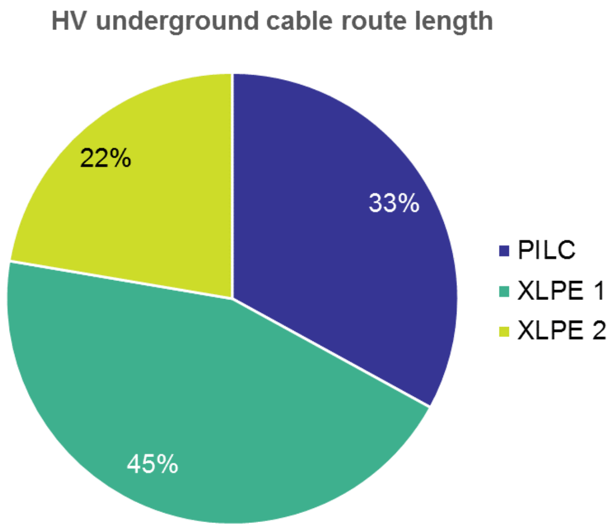
Figure 8 : LV-ABC overhead cable age profile

3.2.3 HV Underground Cables

The sub-transmission HV network associated cables form less than 1% of the insulated cable population length. The majority of the 66 kV circuits are entry cables for zone substations, interconnection of primary assets within zone substations or under-road crossings. They are typically short in length with the entry cables entering a 66 kV switchyard from the bare-overhead/cable-head pole outside the zone substation.

XLPE has been adopted as the standard 66 kV cable insulation material since 1976. There are two types of XLPE insulated HV underground cables, classified by age, as 1st generation (XLPE 1) and 2nd generation (XLPE 2).

Figure 9 illustrates the percentage of each HV UG cable specification out of the total length of HV UG cables. Paper Insulated Lead Covered (PILC) cables comprise 33% of the total HV cable length, an ever decreasing



percentage as the installation of XLPE insulated cables continues.

Figure 9 - 66 kV Underground Cable Population Summary

Figure 10 illustrates the age profile of HV underground cables as percentage of total HV UGC route length.

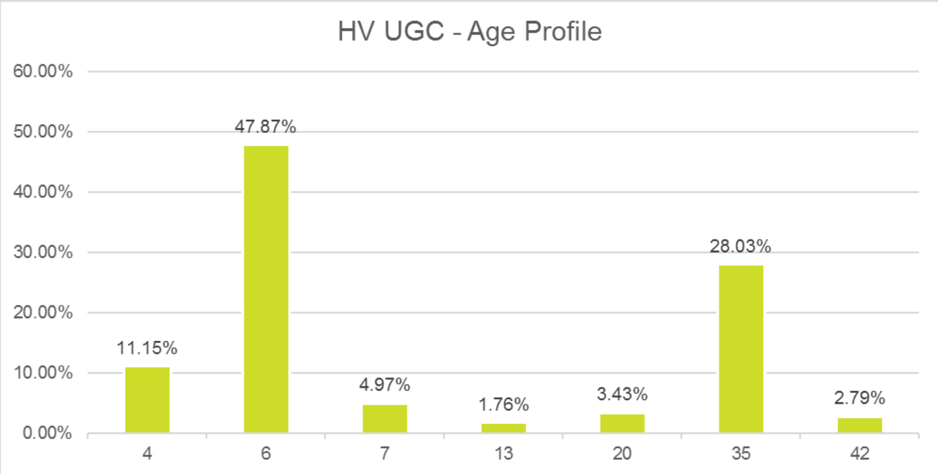


Figure 10 : Age profile of HV underground cables

3.2.4 MV Underground Cables

The MV underground cable network currently comprises over 97% of XLPE insulated cable, the remaining being PILC.

There are three types of XLPE insulation, 1st generation (XLPE 1), 2nd generation (XLPE 2) and Tree Retardant (TR-XLPE) insulation types contributing 29%, 26% and 41% respectively. These types differ in their design specifications with TR-XLPE currently the standard to prevent or retard the growth of water trees within the insulation.

The 11 kV and 6.6 kV underground cables are primarily located in regional high bush fire risk areas (HBRA) and are also installed in the Latrobe Valley open cut mines.

The 22 kV underground cables are generally located in road reserves in URD housing estates. The majority of URD cables are 185 mm^2 or 240mm^2 aluminium three-core XLPE cables, whilst there are also some older paper-insulated three-core cables.

The remaining 22 kV cable fleet facilitate connection to power transformers, capacitor banks, NER's and feeder exit cables that deliver the power from the zone substations.

The older transformer cables are either single-core or 3-core 500 mm^2 copper paper-insulated, with the more recent cables being either 500mm^2 Copper or 800 mm^2 aluminium single-core XLPE-insulated cables. Feeder exit cables are typically short in length and reticulate from a zone substation to a cable-head pole outside the zone substation, from where the feeder typically reverts to overhead construction. Such feeders are then classed as 'backbone' cables until the criticality and/or number of customers connected diminish to lower risk levels.

Most zone substation feeder exit cables are 240 mm^2 aluminium three-core XLPE cables, whilst there are some 185 mm^2 aluminium three-core XLPE cables and some paper-insulated three-core cables.

Figure 11 shows the distribution of insulation type of the MV underground cables.

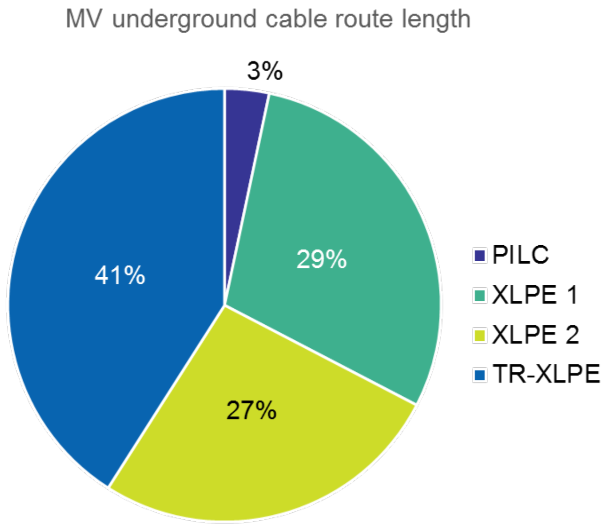


Figure 11 – MV Underground Cables Population Summary

Figure 12 illustrates the age profile of MV underground cables as percentage of total MV UGC route length.

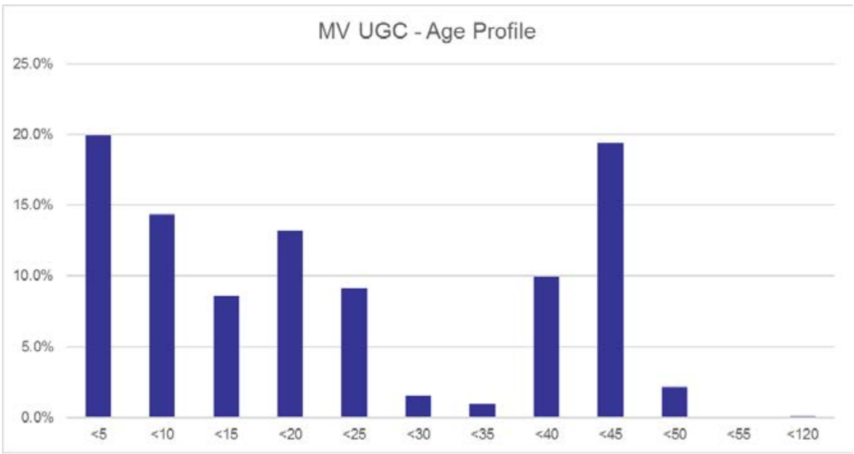


Figure 12 : Age profile of MV underground cables

3.2.5 LV Underground Cables

The low voltage underground cable network constitutes the remainder of the insulated cable population. These cables are primarily located in newer residential estates, connecting kiosk substations to customer's points of supply. This has been the preferred construction technique since the late 1980s. Figure 13 illustrates that 45% of the current available data does not correctly identify the insulation type. However, based on an historical understanding it can be assumed that the majority of this quantity is indeed XLPE insulated, with polyvinyl chloride (PVC) and PILC contributing 16% and <1% respectively.

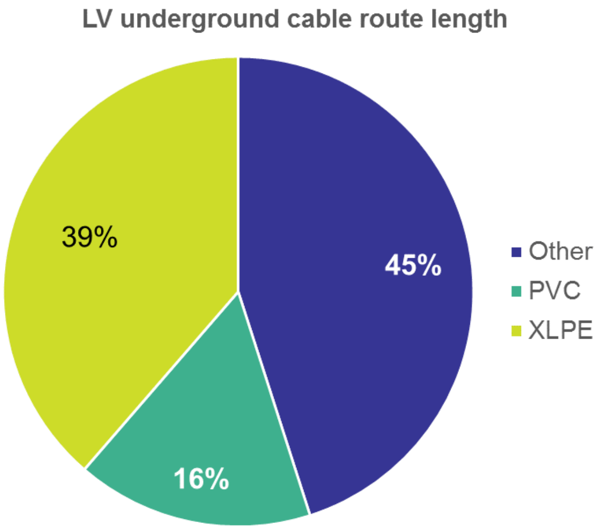


Figure 13 – LV underground cables population summary

3.3 Asset Condition

The condition of a cable system can be primarily determined from assessing the insulation, its accessories (terminations and joints) and any suspension equipment (brackets, grommets, etc.) applicable to overhead systems.

Conditions can be determined by material specific indicators such as a count of the number and severity of defects, visual inspection, and electrical measurements. The asset's lifecycle phase can be derived from indicators such as age, design, type, installation environment and engineering judgements calibrated to failure history.

The existing Condition Score has been based on age and insulation type as the quality and quantity of Asset Management data is not yet sufficient to undertake more detailed assessments.

Condition Scoring Methodology The existing Condition Score is based on age and insulation type			
Condition Score	**Condition Description**	**Summary of condition score**	**Remaining Life**
C1	Very Good	These cables are in good operating condition with no past history of significant defects or failures.	95%
C2	Good	This category includes cables which have a better than average condition.	70%
C3	Average	This category includes cables which have an average condition.	45%
C4	Poor	This category includes cables which have a worse than average condition. For overhead cables, they may have developed an increasing number of local damages from tree impact. For underground cables, they may have developed an increasing number of local damages from third party dig ins, mechanical contact and tree impact at aerial terminations.	25%
C5	Very Poor	This category includes cables which are typically maintenance intensive and have history of supply interruptions. These cables are approaching the end of technical life. The maintenance that can be performed to restore the condition is limited. The maintenance of cables in this category is typically no longer economical compared to asset replacement.	5%

Table 1 – Condition scorecard for insulated cables

Figure 14 illustrates the four main stages in a cable system's lifecycle, Healthy, Deteriorated, Faulty and Failure. When the insulation is 'Healthy', the cable is performing its function. Once the health of the cable has 'Deteriorated', the cable will continue to perform except in extreme conditions. The cable system becomes 'Faulty' when it can perform its functional requirement to withstand operating voltages and currents but cannot withstand voltage surges and over-voltages. 'Failure' occurs when the cable system no longer performs its function.

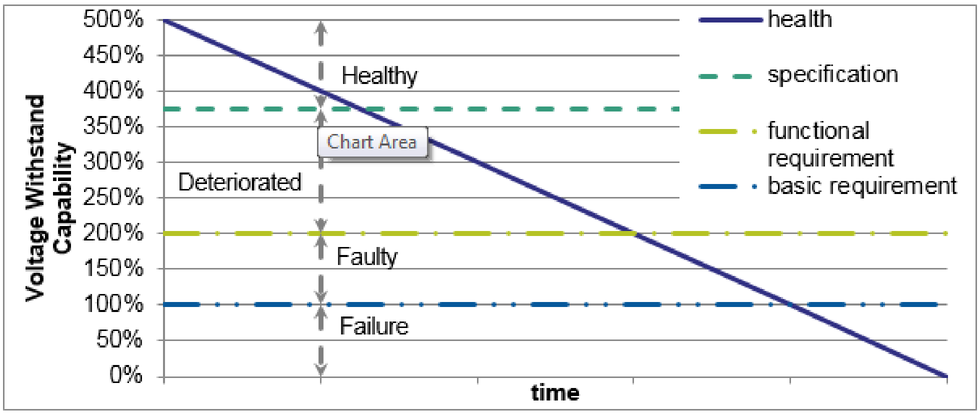


Figure 14 – Cable Voltage Withstand Capability

3.3.1 MV Overhead Insulated Cables

The condition score for all MV overhead cables, except for 22kV NMS HV ABC, was determined from their age, type and the criteria in Table 1.

The condition score for each 22kV NMS HV ABC cable was determined from age, type and the criteria in Table 2.

Condition Scoring Methodology for 22kV NMS HV ABC			
Condition Score	**Condition Description**	**Summary of condition score: Maximum damage to the insulation screen due to sheath arcing**	**Remaining Life**
C1	Very Good	Aluminium oxide marks	95%
C2	Good	Pit depth to 1/4 of the screen thickness	70%
C3	Average	Pit depth to 1/2 of the screen thickness	45%
C4	Poor	Pit depth to 3/4 of the screen thickness	25%
C5	Very Poor	Pits bridge the screen, attack of the main insulation has started.	5%

Table 2 – Condition scorecard table for 22 kV NMS HV ABC cable section

Figure 15 illustrates the overall condition of the MV overhead insulated cables as a percentage of total MV OH cable route length. As the replacement of MV NMS cable progresses, with either LDMS or underground, so to the C5 condition score continues to decrease.

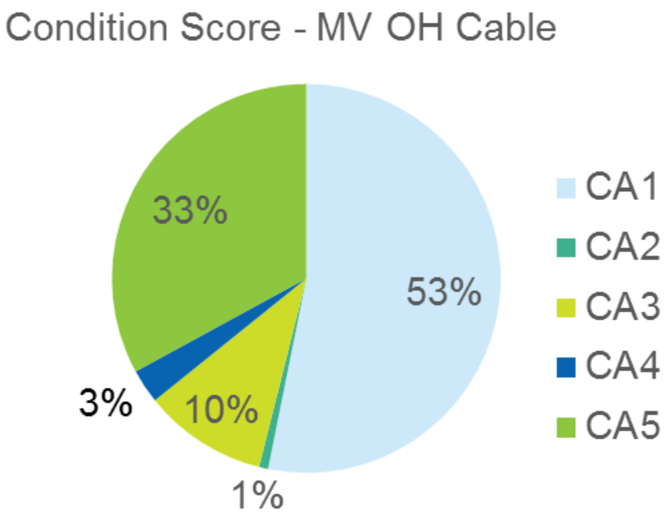


Figure 15 – Condition score summary of the overhead MV cable population.[3]

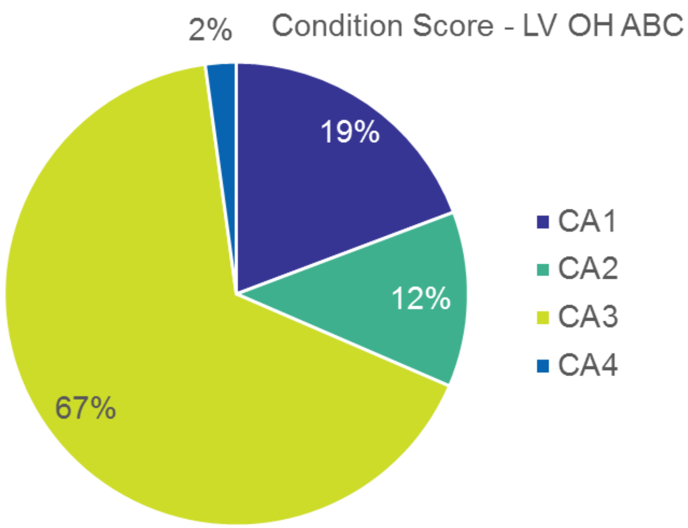
Screen pitting is the primary deterioration process of NMS HV ABC, causing a substantial reduction in the expected service life.

Figure 16 – Screen pitting of the insulation screen of NMS HV ABC caused by sheath arcing.

3.3.2 LV Overhead Cables

The condition score for all LV overhead cables was determined from their age, type and the criteria in Table 1.

Figure 17 illustrates the overall condition of the LV overhead insulated cables as a percentage of LV-ABC total population. This condition assessment has highlighted that the majority of cables in this fleet are in average or better condition, with 99% of this fleet comprising LV ABC.



[3] Refer to AMS Data v1.xlsx

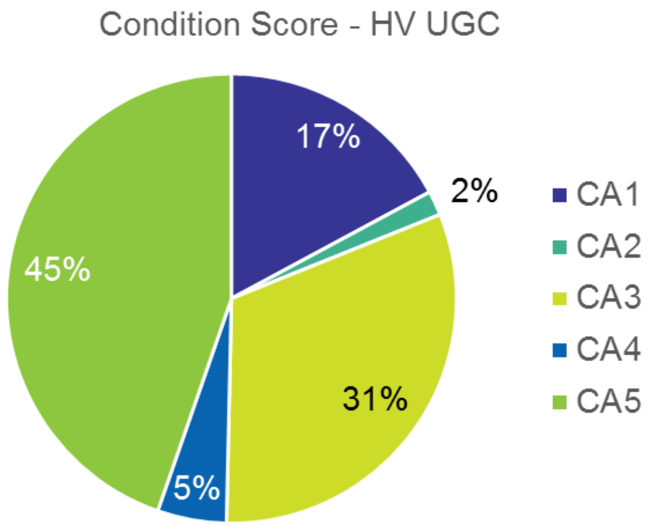


Figure 17 – Condition score summary of the LV OH cable population.

3.3.3 Underground Insulated Cables

Identifying the actual condition of an underground cable is more difficult as visual inspection is not possible. Electrical testing is therefore required to confirm the voltage withstand capability of the cable to its specification. The cable insulation can be highly degraded but it can remain in operation provided voltage is in the normal operating range. Failure will become imminent if there is a voltage spike or a surge.

Acceptance tests are undertaken during commissioning of new assets to ensure that the installed asset is fit for service by adequately measuring the voltage withstand and current carrying capabilities of the entire cable system. Additional tests are completed to determine if any damage to the outer protection sheaths has occurred during the installation process. These tests provide a 'benchmark' or 'fingerprint' of the condition for the insulation and protection layers.

The commission tests form an integral part of the quality assurance system surrounding the correct supply and installation of the cable and accessories. Additionally, they ensure that consistent, high quality installation practices are followed at all times for both the cable system and accessories.

The condition of each cable section has been scored ranging from "Very Good" condition (C1) to "Very Poor" condition (C5) and was determined by applying the criteria in Table 1.

The company is implementing a test program to better define the Condition Assessment of HV and MV underground cable circuits based on electrical measurements.

3.3.3.1. HV Underground Cables

The condition score for HV underground cables was determined from their age, type and the criteria in Table 1.

Figure 18 illustrates the overall condition of the HV underground insulated cables as percentage of total HV route length. This condition assessment has highlighted that the majority of HV underground cables are in "Average" to "Very Poor" condition. This may not actually be the case as no condition assessment testing has yet been undertaken on this population. It is envisaged that the PILC cables will be in better condition than indicated and as there are three longer lengths of PILC cables that dominate the population, once assessments have been done, this scoring should correct itself.

There are several HV underground cables that have recently been installed, showing as C1 on the profile.

Figure 18 – HV underground cable condition.

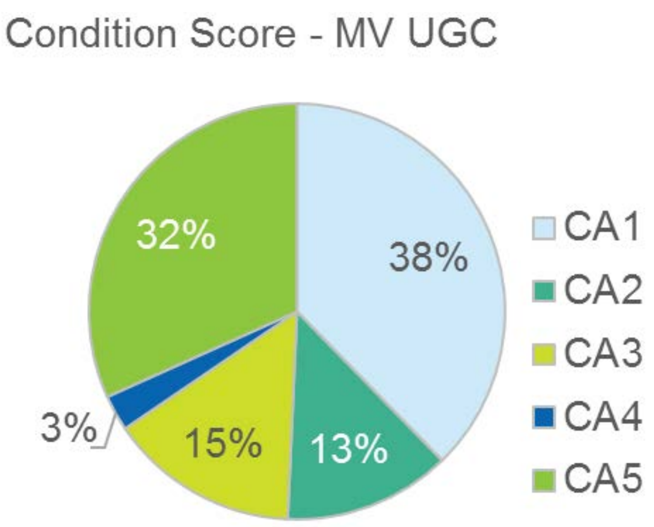
3.3.3.2. MV Underground Cables

The condition score for MV underground cables was determined from their age, type and the criteria in Table 1.

Figure 19 illustrates the overall condition of the MV underground insulated cables as percentage of total MV route length. This condition assessment highlighted that XLPE-1 cables are in the worst condition, which can be expected as they are the oldest technology type in this fleet.

Section will investigate issues associated with this fleet and highlight historical failures and specific issues.

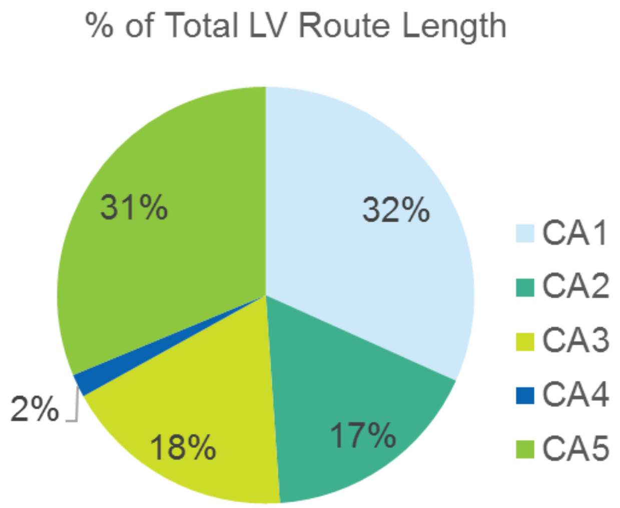
Figure 19 – MV underground cable condition



3.3.3.3. LV Underground Cables

The condition score for LV underground cables was determined from their age, type and the criteria in Table 1.

Figure 20 illustrates the overall condition of the LV underground insulated cables as percentage of total population of LV underground cables. This condition assessment has highlighted that over 65% of the cables in this fleet are in average or better condition. PILC is in the worst condition, but only contributes approximately 1% to the fleet



population.

Figure 20 – LV underground cable condition (excluding service cables and public lighting)

3.4 Asset Criticality

The prevalent consequence of a cable failure is network reliability i.e. interruptions to customer supplies.

The criticality assessment is based on a semi-quantitative evaluation of a cable failure consequence. Three main parameters were considered for each cable segment which combined together illustrate the criticality of a cable segment:

- No. of customers supplied by a cable segment,
- Cable function within the network – i.e. feeder exit, backbone, spur
- No. of joints on an UGC electrical section

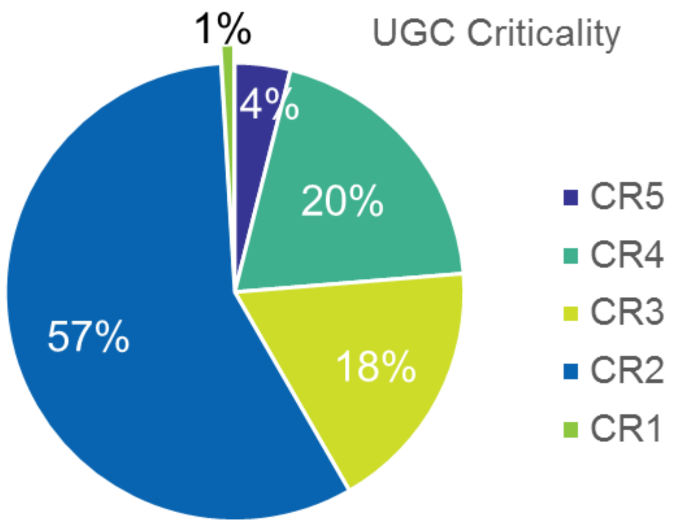


Figure 21 : UGC Criticality - percentage of total HV&MV UGC Network Length

3.5 Asset Performance

Asset performance has been assessed utilising two methodologies

i) Utilising data captured in SAP (desktop Review)

Assessment by analysing the defect notifications by cable component type and fault type. Un-assisted faults are mostly related to the cable specification and its application i.e. cable manufacture, design and installation while the assisted failures are due to network circumstances which were not allowed for in the cable specification and its application i.e. lightning, wildlife, vandalism.

Figure 22 illustrates the distribution of HV&MV faults by UGC component and fault type as a percentage of the total no. of HV & MV UGC faults. The pole mounted cable head fault count is included in the Termination

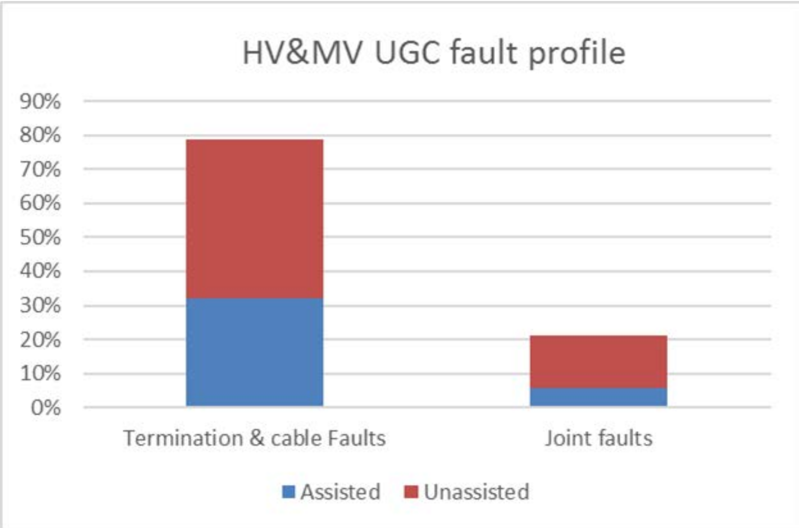


Figure 22 - HV&MV UGC fault distribution

and Cable category.

ii) Utilising results from Condition Assessment testing

Recently, in a program to increase network reliability, a cable replacement strategy has been implemented in order to remove high-risk cables and/or components from the network. To determine which assets pose the greatest risks to network availability, an off-line condition assessment testing program was undertaken on selected cables throughout the network.

Taking cable circuits out of service is troublesome in an operating network. Organising outages, switching and isolations can be difficult in networks where circuits have no redundancy, are highly loaded, have a large number of dependant customers or are just hard to get to. It was for most of these reasons that the majority of the investigations and testing program were undertaken in an area chosen for its seasonal loadings that made obtaining outages for longer periods of time more palatable at certain times of the year.

During the testing programs, many defects were detected, primarily as Partial Discharge (PD) activity in joints and terminations, however there were a few instances of high moisture (DDF) values from the cable.

All test results obtained during the condition assessment test program, have been analysed against acceptance criteria that AusNet Services has developed over many years for aged (>5 years old) cable assets.

In summary, from the 283 cable segments tested rated at 22 kV and aged between 5 to 35 years, there were

- 101 recorded results that failed to pass the Company's acceptance criteria.
- Only one cable failed during the application of the reduced level High Voltage Withstand test
- A DDF failure is seen as a cable failure

- Termination and joint failures accounted for 58% and 33% being respectively
- Of the total tested accessories, 40% exhibited PD at the elevated test voltages, and 26% exhibited PD at or below service voltage.
- In a few cases, cable accessories showed PD activity higher than 10,000pC.
- According to the criteria, such accessories were replaced as part of the test program.
    - The results are displayed in Figure 23

Table 3 – Proposed Condition scorecard for HV and MV Underground Cables

HV and MV Underground Cables: Condition Scoring Methodology			
Condition Score	Condition Description	Summary of condition score	Remaining Life
C1	Very Good	These cables are in good operating condition with no past history of significant defects or failures. Condition Assessment tests have yielded results that indicate no significant defects are present within the cable circuit. High Sheath IR, Acceptable DDF, No detectable PD	95%
C2	Good	This category includes cables which have a better than average condition. Condition Assessment tests have yielded results that indicate no significant defects are present within the cable circuit. Mid Sheath IR, Acceptable DDF, Limited PD in accessories	70%
C3	Average	This category includes cables which have an average condition. Condition Assessment tests have yielded results that assigned to normal ageing of insulation systems. Mid Sheath IR, Higher but acceptable DDF, Higher limited PD	45%
C4	Poor	This category includes cables which have worse than average condition. For overhead cables, they may have developed an increasing number of local damages from tree impact. For underground cables, they may have developed an increasing number of local damages from third party dig ins, mechanical contact and tree impact at aerial terminations. Condition Assessment tests have yielded results that indicate a fail/or near fail of a test criteria Fail Sheath IR, High/Fail DDF, High detectable PD in accessories	25%
C5	Very Poor	This category includes cables which are typically maintenance intensive and have a history of supply interruptions. These cables are approaching the end of technical life. The maintenance that can be performed to restore the condition is limited. The maintenance of cables in this category is typically no longer economical compared to asset replacement. Condition Assessment tests have yielded results that indicate a major defect that requires immediate action. Fail Sheath IR, Fail DDF, High detectable PD in accessories (>10,000pC) or detectable PD activity within a cable segment.	5%

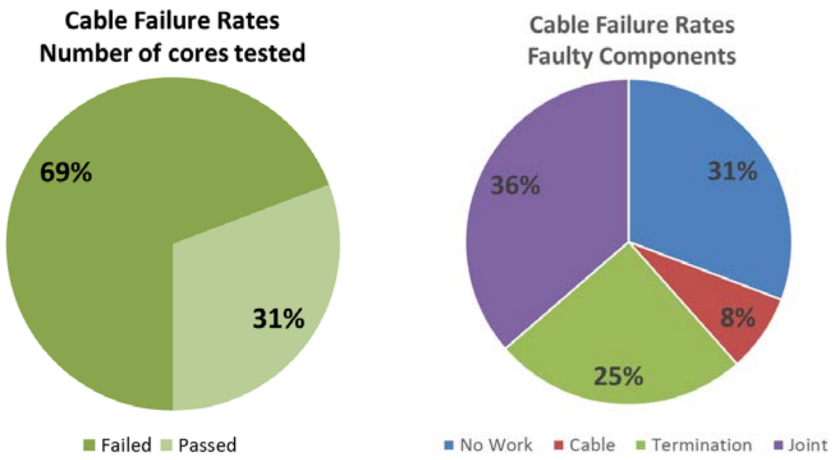


Figure 23 : Condition Assessment results for selected MV cable circuits

4 Other Issues

4.1 Legislation and Regulatory Requirements (REFCL)

AusNet Services' network operates in a unique geographical location, some of which is exposed to extreme bushfire risk. These conditions warrant significant investment to mitigate the risk of bushfires as a result of earth faults on the distribution network risk.

The 2009 Victorian Bushfire Royal Commission made several recommendations with respect to fires initiated from distribution electricity networks. Subsequently, the Victorian Government established the Powerline asset Bushfire Safety Program to research the optimal way to deploy Rapid Earth Fault Current Limiter (REFCL) devices for bushfire prevention. This research led the Government to introduce Electricity Safety (Bushfire Mitigation) Amendment Regulations 2016.

For AusNet Services, the regulations require each polyphase electric line originating from 22 selected zone substations to comply with mandated voltage reduction performance standards by 1 May 2023. In the timeframes specified in the regulations, the installation of REFCLs is the only feasible technological solution.

The REFCL installation program will be managed in three Tranches. As the majority of the work will have either been completed or planned in detail by this EDPR period, this strategy document only presents an outline of the REFCL program and strategy.

The REFCL strategy is concerned with the high voltage and condition assessment testing of the underground cables that will be directly affected by the increased voltages imposed by the new REFCL technology. This is a once-off set of condition assessment tests attempting to identify a cable's capability of withstanding the over-voltages that will imposed on it during the operation of a REFCL device.

The cables affected will either be connecting assets within the station or will be feeder exits.

MV underground cables connected to a REFCL protected network (high impedance earthing) must be capable of sustaining the elevated voltages that occur on the two healthy phases in response to a phase to ground fault on the third phase.

Sustained over-voltages will be experienced regularly and repeatedly during REFCL operation.

4.2 Cable Condition Assessment

A new Condition Assessment (CA) program has been developed to support the company's Risk Based Asset Management (RBAM) program, to start to move away from a fundamentally reactive maintenance program to a more proactive approach to addressing cable circuit defects. The new program has two areas of focus

- On-line testing
  Allowing the circuit to remain in service while identify any obvious defects with terminations by visual inspection and attempting to detect significant electrical defects within the circuit by using sophisticated non-invasive monitoring equipment.

- Off-line testing

  Incorporating a wide variety of electrical test methods to accurately detect defects at normal and over-voltage conditions. The Company has developed and started to implement a condition assessment program for its HV and MV underground cable population. This program consists of a suite of electrical diagnostic tests that can yield an economical and accurate assessment of the overall condition of a cable circuit.

From such tests, defects can be identified and a planned works program can be established to replace the defect in a timely, cost effective, proactive manner.

Refinement of this program will continue during the EDPR period

An example of the off-line test program undertaken within the Victorian Alpine areas is shown in Figure 24. Similar programs will be rolled out in the other areas across the AusNet Services Victorian distribution network.

The data obtained from these testing programs will be utilised to establish

- A more robust condition scoring methodology for underground cables.
- Mean Time To Failure (MTTF) and Mean Time Between Failure (MTBF) per cable type

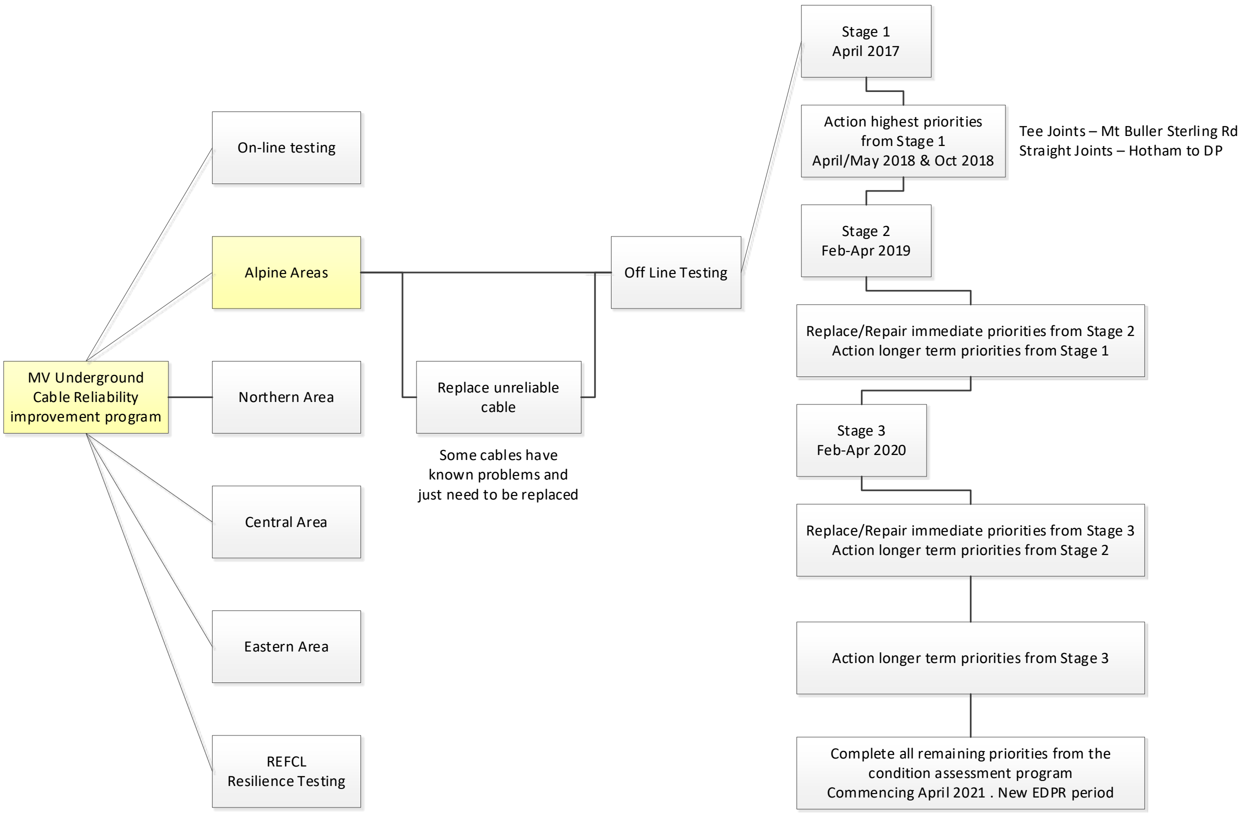


Figure 24 - Detailed testing program for Alpine Areas

During the EDPR it is planned to maintain a constant utilisation of the available testing resource, therefore as the requirements for REFCL testing begins to decrease, the testing of these critical, high condition score assets will begin to increase.

Year	2018	2019	2020	2021	2022	2023	2024	2025
Total Cable tests	**210**	**210**	**210**	**210**	**210**	**210**	**210**	**210**
Proactive Safety Testing (REFCL)	120	120	120	100	100	20	0	0
Proactive General Network Testing	50	50	50	70	70	150	170	170
Proactive retests as a result of replacements	20	20	20	20	20	20	20	20
Reactive testing	20	20	20	20	20	20	20	20

5 Risk and Options Analysis

This section outlines the key risks associated with HV and MV underground cables and discusses how those risks should be addressed.

5.1 Risk Assessment Methodology

The risk assessment methodology is a semi-qualitative assessment and considers the probability and consequence of a failure for each MV underground cable segment.

The probability of failure is directly related to the individual cable segment condition assessment score and the consequence is determined by considering following criteria:

- Cable function/role in the network,
- Number of customers supplied by the cable segment and

This risk assessment excluded all REFCL cable segments as they will be addressed by the REFCL program

Figure 25 and Figure 26 summarise the underground cable risk matrix by providing percentage of critical cables out of total cable route length and total no. of cable segments respectively.

		Condition Score					
		C1	C2	C3	C4	C5	Grand Total
Criticality	5	0.3%	0.3%	1%	2%	0.5%	4%
	4	8.7%	1.0%	2%	0.1%	8%	20%
	3	7.6%	1.7%	2%	0%	6%	18%
	2	0.2	0.1	8.3%	0.8%	19.8%	57%
	1	0.0	0.0	0.3%	0.1%	0.0%	1%
	Grand Total	35.7%	13%	13%	3%	35%	100%

Figure 25 : MV und erground cable criticality based on circuit length

		Condition Score					
Criticality		C1	C2	C3	C4	C5	Grand Total
	5	0.3%	1%	7%	2%	1%	10%
	4	7%	1%	2%	0.1%	6%	15%
	3	7%	2%	2%	0%	7%	18%
	2	0.2	0.1	9%	1%	22%	55%
	1	0.0	0.0	0.4%	0.2%	0.1%	1%
	Grand Total	30%	12%	20%	4%	34%	100%

Figure 26 - MV underground cable criticality based on number of segments

5.2 Replacement Forecast

There are approximately 625 cable segments that have the highest Criticality and Condition Score, equating to 9% of the overall network cable segments or 10.5% of the network length. During the EDPR period it is planned to test, repair/replace and then retest as required this entire population.

Based on previous testing experience from the REFCL and Alpine test programs, it is estimated that this testing program will result in the need to replace approximately 11km of cable route and approximately 50 cable joints and/or terminations.

The reactive maintenance component of this program was estimated based on the historic trend.

There is no proactive forecast for covered conductors during this EDPR period

6 Asset Strategies

6.1 New Assets

Where practical, the vast majority of new installations will use underground cable circuits, rather than ABC configurations. While no additional overhead insulated cable systems are being planned in the future, any repaired or replaced installations will utilise LDMS HV ABC. The preference remains to underground such circuits where economically viable, thus removing all risk of tree damage and fire starts, to raise the circuit reliability and to improve the streetscape. Replacement programs will continue to eliminate all NMS ABC MV overhead cable from the network.

As the cable network continues to be renewed because of either in-service failures, condition assessment results, high condition score or REFCL testing outcomes, the population of PILC cables will diminish until eventually they will no longer exist on the network.

All new cable systems shall be subjected to the commission test protocols that have been developed. SMI 12-01-02

In order to minimise the effect of poor installations and to ensure the maximum cable circuit reliability, the following measures have been or are being implemented

- Using only accredited installers, trained by the specific accessory manufacturers
- Where practical, designing (and repairing) of all cable circuits to have no joints

6.2 Inspection

Non-invasive inspection and testing methodologies can be utilised on in-service assets to determine the presence of outward signs of a deteriorated inward condition. Simple things like an oil leak on a HV cable termination can lead to a catastrophic failure if left unchecked.

6.3 Maintenance

The following maintenance activities will continue to be refined

- Recording of fault codes to enable disaggregation of failure modes by cable or accessory type
- Fault data collection for each cable failure to determine root cause of the failure and enable trending
- Recording of installers/jointer details to improve efficiencies

Maintenance strategies of insulated cables are voltage and environment dependant

LV cables

- Both overhead and underground, will continue to be replaced on condition as determined by the criteria in Table 1, or earlier if they fail in service or are replaced during network upgrade works

MV underground cables will continue to be maintained in the following traditional manner

- Critical cables, as defined in the testing Standard Maintenance Instruction (SMI), within stations shall have no joints. Temporary joints may be permitted for a period of no greater than six months to enable supply to be restored
- Following an in-service failure of cable and/or in-line joint, the failed portion shall be cut out and replaced with two joints and a short length of new cable
- A HV customer supply cable that has a circuit length less than 100m shall be replaced rather than repaired
- Termination failure, where enough spare length cannot be recovered from the cable, will have a new inline joint installed within 4 metres of the base of the pole and a new tail length of cable installed and terminated

- MV PILC cable failures, and possible subsequent testing, will preferably cause the entire cable circuit to be replaced. If this is uneconomical then the repair shall be covered by the above two XLPE methodologies except that the joints to be used will be transition/sealing joints to ensure that the paper/oil system is sealed.
- HV Oil Filled Cable (OFC) failures will again preferably cause the entire cable circuit to be replaced. If this is uneconomical then the repair shall be covered by the above two XLPE methodologies except that the joints to be used will be stop joints to ensure that the paper/oil system is sealed and pressurised.

6.4 Obsolescence and Spares Management

- Due to the large volume turnover of LV and MV insulated cables, the strategic spare holding levels for such cables is minimal. There is always stock within the stores systems that can be used to respond to failures
- There are some MV underground cable circuits that have a slightly different design than those typically used. These design differences usually dictate that a strategic spare be on hand should a failure occur.
  - Two examples that might help understanding are larger screen wire cross section to carry higher fault ratings in a particular installation or a special outer protective sheath construction. For such cables at least one drum of strategic spare cable would be deemed necessary in order to facilitate the correct repair.
- HV cable circuits are typically bespoke designs for particular applications and as such would dictate the carrying of strategic spares of both cable and possibly accessories. The number of spare joints, if required, shall be sufficient to facilitate the repair of the three phase circuit.
- While HV Oil Filled Cables exist on the network, strategic spare transition and stop joints are required. Again the preference is to replace these cable circuits, however due to long circuit lengths such replacements may not be economically viable. In such cases the required number of joints shall be sufficient to facilitate the repair of the three phase circuit without the need to have to replace the entire cable.
- Periodic refreshment of the spares maintenance policies is an ongoing activity.

6.5 Refurbishment

Replacement, rather than refurbishment, is the only viable option in regards to LV, MV and HV cable systems.

6.6 Replacement

Continue replacement of MV Overhead NMS ABC with LDMS.

6.7 Research and development

Continue to explore economics of alternative overhead covered conductor solutions