Conductor

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 outline the inspection, maintenance, replacement and monitoring activities identified for economic life cycle management of bare conductors in AusNet Services' Victorian electricity distribution network.

This strategy applies to bare overhead conductors including those operating at LV (415 V), MV (22 kV, 11 kV and 6.6 kV) and HV (66 kV) circuits. Both bare conductor as well as conductor hardware is included in this strategy.

There are 38,208[1] km of bare overhead conductor across the entire distribution line network. Close to 60% of the MV & HV bare conductor route length is steel followed by ACSR amounting to 21%, Aluminium 19% and Copper 1%. The LV network consists of 39% of the entire LV route length as ACSR conductor,followed by 26% Aluminium, 18% Steel and 17% Copper bare conductor.

Condition assessment shows that more than 75% of the entire network route length is in good condition (C1&C1), 21% in Average condition (C3) and the reminder of 4.2% in bad or very bad condition (C4&C5).

The consequence of conductor system failure has been assesed. It is estimated that 11% of the total network route length is in very high criticality and 30% in high criticality bands.

The risk assessment methodology considers as input the probability of failure, consequence of failure, cost of replacement and it calculates the benefit of conductor replacement for each wire segment in the network.

A comphrehensive quantitative risk assessment suggestes that for the 2021-2025 reset period it is recommended to proactively replace 3.5% of the network route length in the poor condition and high consequence parts ot the network.

Proactive management of conductor application, inspection, maintenance, refurbishment and replacement practice is required to ensure that stakeholder expectations of cost, safety, reliability and environmental performance are met.

1.1 Strategies

The following strategies shall be used to manage risks associated with conductors, line ties, conductor joints, armour rods, vibration dampers and spacers.

1.1.1 New Assets

- Utilise LV ABC cable systems for all new aerial LV circuits constructions.
- Utilise insulated underground cable, HV ABC or covered conductor cable systems for new MV circuits in codified areas.
- Utilise underground cable, HV ABC or covered conductor cable systems for new MV circuits in high Fire Loss Consequence areas on a case by case basis.
- Utilise AAC and ACSR bare conductors for new aerial MV circuits in low bush fire risk areas and in low Fire Loss Consequence areas.
- Utilise AAC and ACSR bare conductors for new aerial 66 kV circuits.
- Install armour rods and vibration dampers in accordance with AusNet Services' published technical standards.
- Utilise clamp top insulators and armour rods for all new construction.
- All new REFCL feeder overhead conductors will be three phase capacitive balanced.

1.1.2 Condition Inspection

- Assess conductor, conductor tie, conductor joints, armour rods, vibration dampers and conductor spacer condition in accordance with the criteria established in the Asset Inspection Manual, 30-4111.
- Continually assess the condition of all bare conductors and maintain accurate condition status in the Asset Management Information System.

1.1.3 Maintenance

In conjunction with other maintenance works:

- Replace McIntyre and Fargo sleeves (if any left) with compression sleeves and helical splices.
- Replace PG clamps on HV circuits (if any left) with Wedge type connectors.
- Replace LV spreaders on LV spans in high bush fire risk areas in accordance with AusNet Services' standard VX9/7020/150.
- Replace deteriorated line ties in accordance with the criteria established in the Asset Inspection Manual 30-4111.

1.1.4 Replacement

- Replace deteriorated assets in accordance with the criteria established in the Asset Inspection Manual
- Replace deteriorated MV bare conductors circuits in codified areas with underground cable, HV ABC or covered conductor cable systems.
- Replace deteriorated MV bare conductors circuits in high Fire Loss Consequence areas with HV ABC or covered conductor cable systems on a case by case basis.
- Replace deteriorated MV bare conductors in LBRA and in low Fire Loss Consequence areas with AAC and ACSR bare conductor.
- Replace deteriorated 66 kV bare conductors with AAC and ACSR bare conductors.
- Proactively replace approximately 1,292 km route length of poor condition conductor between 2021 to 2025 to manage bushfire ignition risk, conditional asset failures and mitigate reliability impacts.

1.1.5 Research and Development

- Research, develop and implement objective condition assessment criteria, based on forensic analysis, for AAC and ACSR conductors.
- Consider using SAIP technology to inspect 66 kV conductors supported by sub transmission towers.
- Improve steel conductor condition inspection in line with current industry practices.

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 bare overhead conductors and associated fittings.This document is intended to inform asset management decisions and communicate the basis for activities.

In addition, this document forms part of the Asset Management System for compliance with relevant standards and regulatory requirements. This document demonstrates responsible asset management practices by outlining economically justified outcomes.

2.2 Scope

This strategy applies to all bare overhead conductors including those operating at LV (415 V), MV (22 kV, 11 kV and 6.6 kV) and HV (66 kV) circuits.

Aerial Bundled Cable (ABC) is not part of this strategy and is included in a separate document, AMS 20-65.

For strategies of assets which provide structural support of the conductor refer to documents:

AMS 20-70 Pole,

AMS 20-57 Crossarms,

AMS 20-66 Insulators – High and Medium Voltage.

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

- Conductors in the electricity distribution network are the “electricity avenue” conducting electricity from zone substations to consumers and embedded generators. Their main function is to electrically connect the zone subs to the electricity users. However they need to meet specific electrical and mechanical characteristics in ortder to fulfil their function in a safe and reliable fashion. From an electrical perspective they need to have the required current carrying capacity for the respective area of the network and from a mechanical perspective they need to withstand the electric and mechanical forces i.e. stringing tension, thermal heating, short circuit and ambient induced forces while maintaining the safe electrical clearance to each other, earthed structures and to ground.

3.2 Asset Population

- During the 1980’s the former State Electricity Commission of Victoria (SECV) rationalised the range of standard conductors utilised on the network. This was done in an effort to increase efficiency through standardisation of materials and network design. As a result, All Aluminium conductors (AAC) and Aluminium Clad Steel Reinforced (ACSR) replaced Copper conductors (Cu) and Steel Aluminium Clad (SC/AC 3/2.75) replaced Steel Galvanised (SC/GZ 3/2.75) as standard conductors. Copper was declared obsolete and no-longer used in new construction. See Appendix 1 for a full list of standard conductors.
- ACSR is preferred over AAC for replacement work where long spans are involved. AAC would require additional poles to be installed to reduce span lengths which would increase costs and make this option less economical.
- Conductor systems involve a range of conductor fittings with various functions. Spacers mitigate the risk of conductor clashing on long spans, armour rods protect the conductor against abrasion, vibration dampers prevent damage due to laminar wind induced forces, repair rods and compression splices address broken strands and conductor breakage , tie wires and helical terminations connect conductors to insulators.

3.2.1 Bare Conductors

- AusNet Services employs approximately 38,208[1] km of bare overhead conductor in the electricity distribution network in the eastern part of Victoria. This conductor forms over 400,000 spans of low voltage (LV), medium voltage (MV) and high voltage (HV) circuits as shown in Figure 1.

[1] 2018 AusNet Electricity Services Category Analysis

Conductor

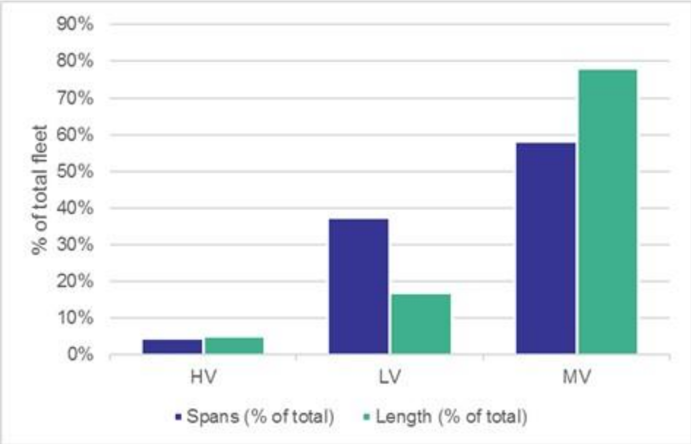
- 

Figure 1 – Bare conductor population by operating voltage

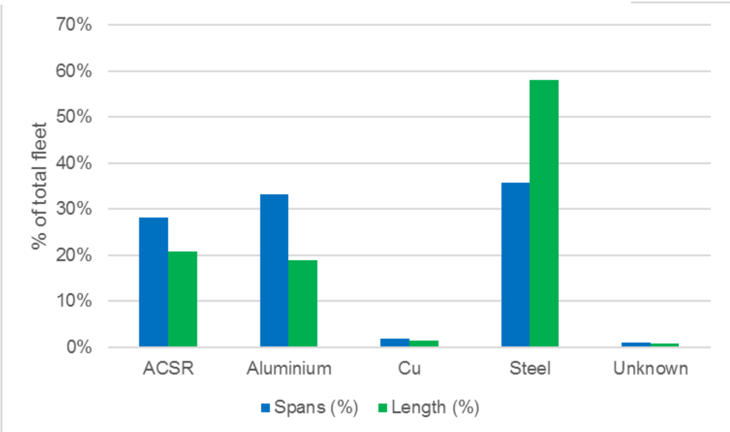


Figure 2 – MV & HV bare conductor population by material

- There are four main categories of conductor material: steel galvanised or aluminised (SC/GZ, SC/AC), ACSR, AAC and Cu. These are summarised in Figure 2 and figure 3[2].
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- The environment corrosivity affects the expected asset lifespan, particularly on steel and ACSR conductors. Hence, the network is categorised into four corrosivity zones. Accelerated section loss was observed on steel and ACSR conductors in high and very high corrosive environments.
- Figures 4 to 7 [2] depict the distribution of conductor population by corrosivity area for each

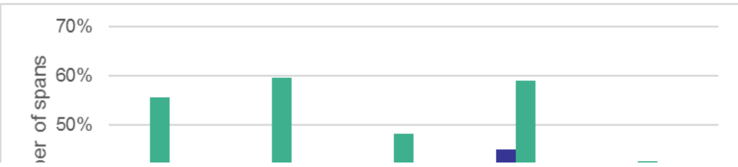

Figure 3 – LV Bare conductor population by material

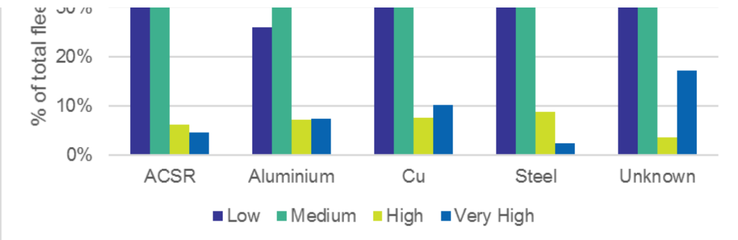

Figure 2 – MV & HV bare conductor fleet by corrosivity zone

[2] AHR 20-52 Bare Conductor Asset Hralth Report

material type.

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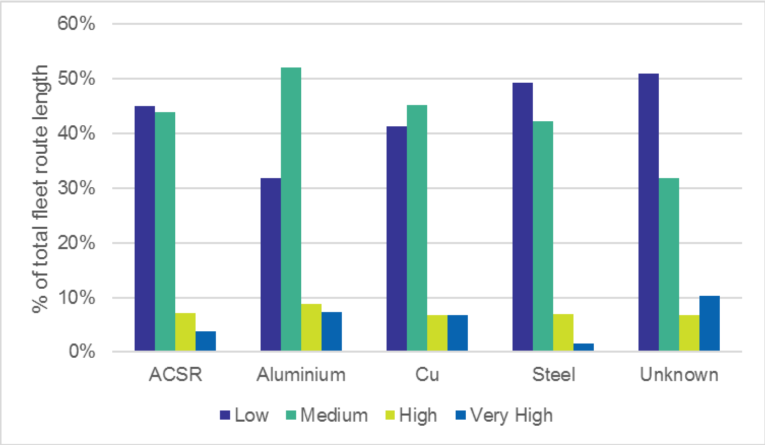

Figure 3 – MV & HV bare conductor fleet by corrosivity zone

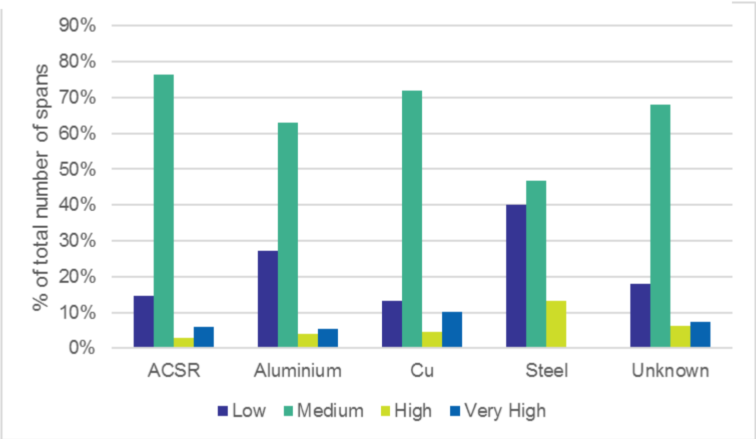

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Figure 4 – LV Bare conductor fleet by corrosivity zone

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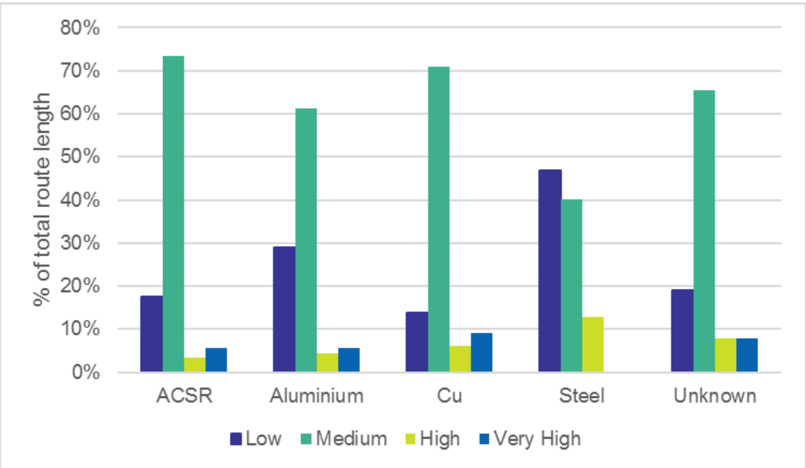

Figure 5 – LV bare conductor fleet by corrosivity zone

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3.2.2 Conductor Tie

Conductor ties are used to secure conductors to pin type and post type insulators.

All new and replacement post insulators are clamp top insulators, progressively removing the need to use conductor ties. Currently the clamp top insulators represent 17% of the insulator population.

3.2.3 Joints

There are several types of joints installed on the AusNet Services network such as helical splices, compression sleeves, McIntyre sleeves and Fargo sleeves. Their use is prescribed in the Standard Installations Manual, 30-4142 and the Standard Maintenance Guidelines, SOP 70-03.

Table 1 shows which type of joints used for different conductor materials:

When a conductor fails due to falling vegetation, it is usually repaired by means of a full tensioned joint. This is a more economical alternative to replacing the entire span of conductor. Joints are not recorded in the asset management system. Furthermore, they are removed when the conductor is replaced which makes it difficult to estimate the volume of joints existing on the network.

Table 1 - Joint types on the AusNet Services network

Material	Tensioned joint	Bridging
Copper	Copper Fargo*, McIntyre* or compression joints	Copper compression sleeve, split bolt
AAC, 6/1 ACSR	Aluminium McIntyre* or compression joints	Wedge connector
3/4 ACSR	Aluminium McIntyre* sleeve or Helical splice	Aluminium PG Clamp
Steel AC	Helical splice	Aluminium PG Clamp
Steel GZ	Helical splice	Steel PG Clamp

* not used on new installations due to corrosion issues

- Non-tension joints, used in conjunction with pole top structures, include Split Bolt clamps, Wedge connectors and Parallel Groove (PG) clamps. Since the 1990's, PG clamps were progressively replaced with Wedge connectors which are now the standard non-tensioned joint for AAC conductors. Steel PG clamps are used for steel conductors, and Aluminium PG clamps are used for SCAC and ACSR conductors.

3.2.4 Spacers

- Spacers or spreaders are used to separate different phases of conductor to prevent flashover and conductor clashing. They are used on LV, MV and HV circuits in HBRA and LBRA areas and are made from non-conductive materials.
- The fitting of fibreglass spreaders to low voltage conductor spans in high bush fire risk areas is a key fire ignition prevention action that was initiated and undertaken post the 1983 Ash Wednesday fires. Asset inspection criteria established around 1983 has ensured that assessment for LV spreaders in HBRA is fully compliant. Only routine maintenance and ad hoc replacement is required.
- A conductor spacers installation program was successfully completed in November 2018 in line with the 2011 ESV Directive to VESI standard VX9/7020/150.

- The program ensured the separation between MV phases and circuits is in accordance with document C(b)1 – Guidelines for Design and Maintenance of Overhead Distribution and Transmission Lines.
- The spreaders are of fibreglass construction and are prone to deterioration over time. Accordingly, asset condition will continue to be monitored through normal cyclic inspection and replaced as required. An additional point for asset inspectors to observe is potential conductor wear caused by the spreader conductor clips.

3.2.5 Armour Rods and Vibration Dampers

- Armour rods are used to protect conductors by providing a protective shield at the point of contact. Vibration dampers are used to prevent wind induced vibration which may impact the conductor.Together ARVD's reduce the conductor vibration and mitigate the mechanical damage to conductor.

Subsequent to the 2009 Victorian Bushfires Royal Commission recommendations, ESV issued a Directive, dated 4 January 2011, for AusNet Services to prepare a plan for the fitting of vibration dampers and armour rods to the entire distribution overhead network in accordance with the VESI standards[3]. The Directive requires the plan to address the program in two broad stages as follows:

- Stage 1 – HBRA before 1 November 2015.
- Stage 2 – all other areas by 1 November 2020.

The program ensured that the highest risk areas are addressed in Stage 1 of the program in accordance with the Directive. Remaining HBRA assets are addressed together with remaining assets in Stage 2.

In total both Stage 1 and 2 included 140,625 sites to be retrofitted with AR & VD's.

Stage 1 retrofitted 42% of the total volume of sites and was completed by 1st November 2015.

Stage 2 is in progress well ahead of schedule with a reminder of 11% of the total no. of sites to be completed by 1st November 2020.

3.3 Asset Age Profile

The service age profile for bare conductors shown in Figure 6 is based on the known and derived installation dates of the fleet of bare conductors.

Recent conductor replacement programmes are responsible for the under fifteen year old population. The fifty to fiftyfive year old peak prompts us to continue the conductor replacement program into the future reset period.

[3] Victorian Electricity Supply Industry Overhead Line Manual, Volume 1, Drawings VX9/7037 and VX9/7037/1.

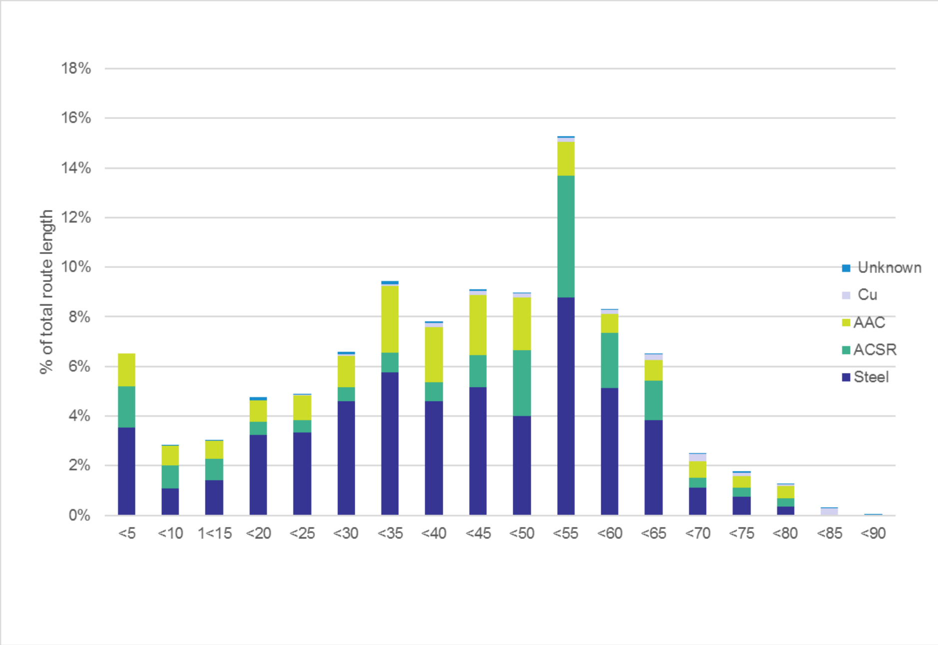

Figure 6 - Service age of bare conductors

3.4 Asset Condition

Condition ratings are assigned for steel conductor based on visual assessments by trained asset inspectors using the Steel Conductor Assessment Guide 4111-6.3. In particular, the amount of protective galvanising, surface rust and cross sectional loss are used to categorise conductor into one of the 5 condition ratings. Additionally the number of work orders (performance history), location corrosivity score and conductor specification are used to complement the site inspections.

For all remaining conductor, condition ratings are determined by a combination of number or work orders, location corrosivity score and conductor specification. The condition scoring methodology can be found in the Asset Health Report (AHR) for bare conductor[2].

There are five different condition scores that have been applied to bare conductors, ranging from “Very good” (C1) to “Very poor” (C5). Table 2 describes the attributes, which determine the condition score rating.

Table 2 – Condiiton Monitoring Methodology

Condition Scoring Methodology			
Condition Score	**Condition Description**	**Summary of Condition Score**	**Remaining Life**
C1	Very Good	• Good condition. No known issues identified.	90%
C2	Good	• Relatively new. No known issues identified.	75%
C3	Average	• Average condition. Some minor defects identified. Early signs of deterioration in condition or performance identified.	50%
C4	Poor	• Approaching end of their economic life. Demonstrate declining performance and are prone to failure.	25%
C5	Very Poor	• Assets with advanced deterioration, high failure rates and lower performance compared with other insulators.	10%

Figure 7 and Figure 8 show the distribution of condition ratings for each conductor material by percentage of total number of spans and percentage of total route length of same conductor material respectively.

Copper and steel have the highest percentage in poor (C4) condition. There are very few assets in very poor (C5) condition.

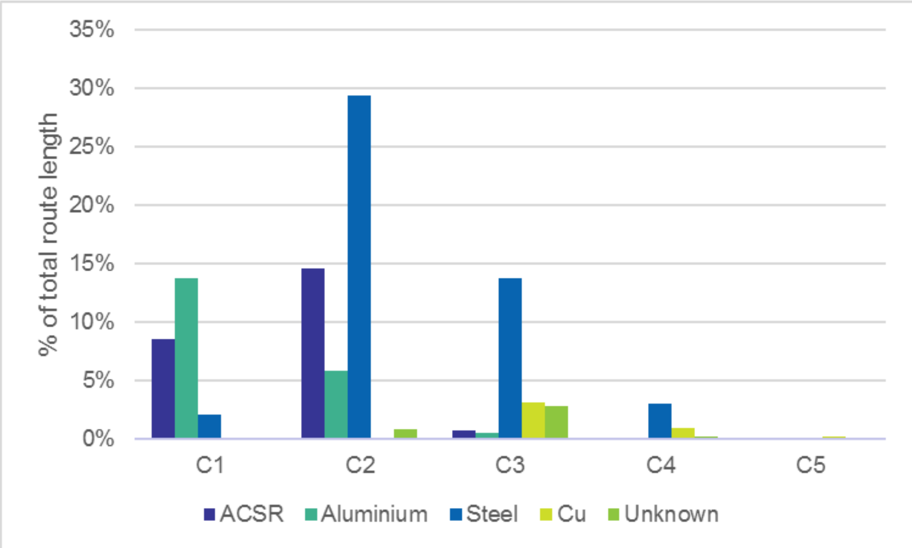

Figure 7 – Condiiton score by material type

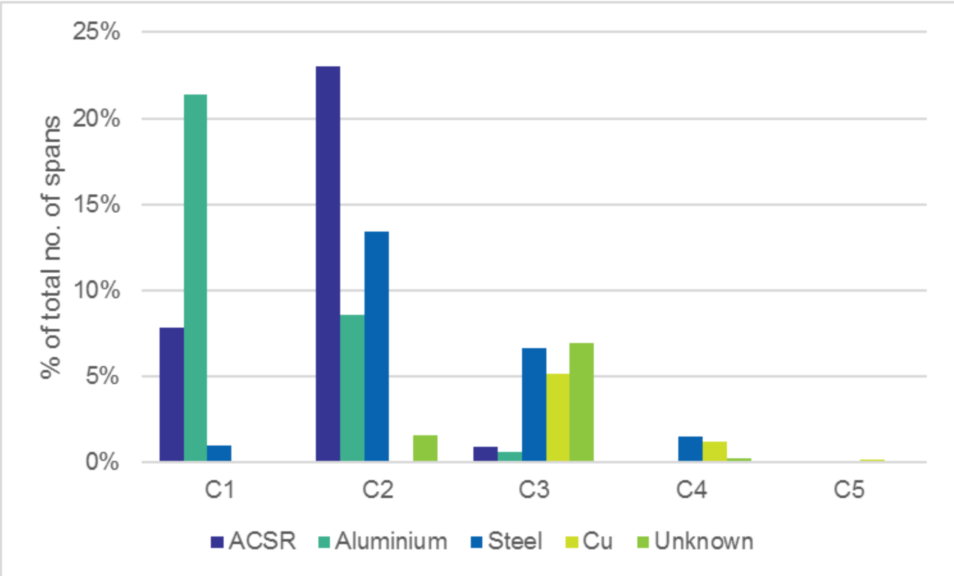

Figure 8 – Condition score by material type

3.4.1 All Aluminium conductor

AAC is used mostly in Urban areas (shorter spans and high current load) which are usually located in Medium or Low Corrosivity zone. AAC is rarely used in rural areas which are usually characterised by low current load and long spans and usually located in High and Very High Corrosivity zones.

The condition profile for aluminium, as shown in Figure 9, suggests that AAC is in good condition compared to all other types of conductor as more than half of the fleet is in C1. This is mainly due to:

- Aluminium is relatively new compared to Steel and Copper,
- There is a low number of workorders which involve repairing AAC spans,
- The highest contribution to the condition score is made by the no. of workorders
- The inspection of AAC conductors is done on a binary choice: damaged or undamaged,
- AAC is not impacted by corrosivity of the environment.

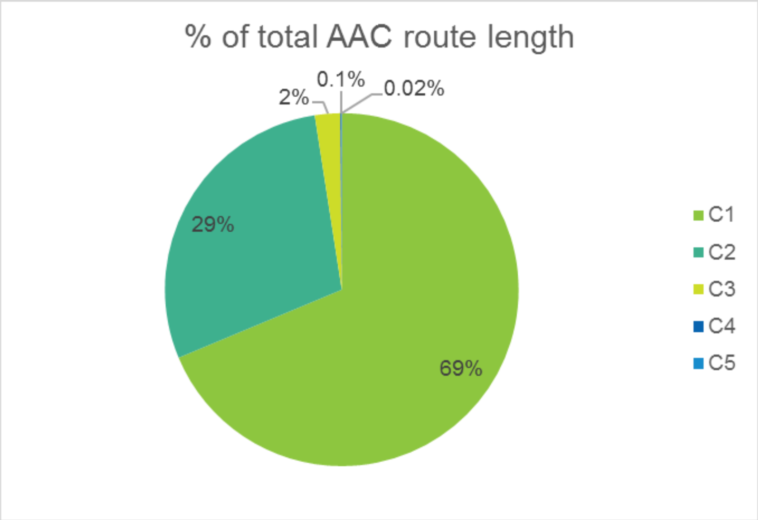

Figure 9 –AAC condition profile

3.4.2 ACSR conductor

The ACSR conductor offers a compromise between steel and aluminium. It has higher current carrying capacity than steel and greater breaking load than aluminium allowing for feeder applications with longer spans than aluminium and higher current load than steel. The ACSR spans are mostly located in Medium corrosivity area.

The condition profile for ACSR, as shown in Figure 10, has over 95% of the fleet in condition grades C1 and C2. The main contributors to C4 & C5 score spans is the work order count and the main contributors to the C2 & C3 score spans is the obsolence of the conductor stranding (imperial size) and corrosivity of the environment.

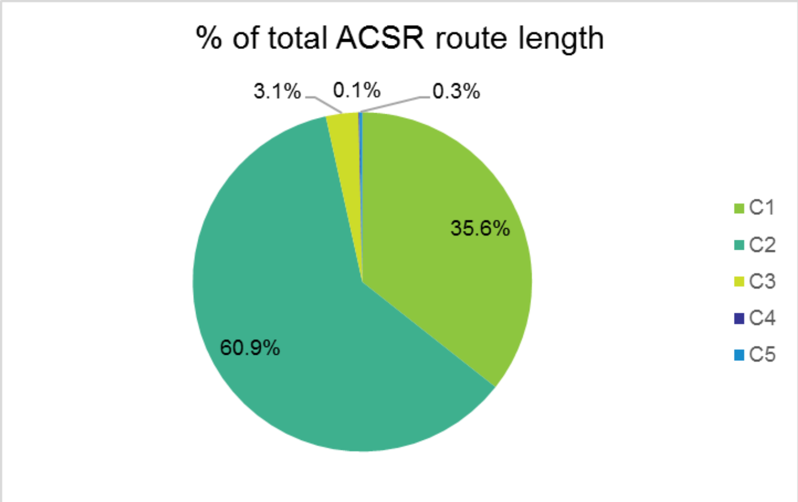

Figure 10 – ACSR condition profile

3.4.3 Copper

Copper conductor was used at the beginning of the electrification hence it is very old compared to other conductor materials. It features the highest current carrying capacity and shortest span length designs.

Experience indicates that Copper conductor located in warmer and drier climates show little signs of deterioration. This is reflected in the fact that none of the copper conductor spans with condition rating 5 are located in the North region. Conversely, Copper located in wetter regions has been observed to undergo blackening as shown in Figure 11. Removal of black scale reveals pitting of the conductor strands which also become brittle. This presents a risk of unexpected conductor failure. Such failures have also cascaded with subsequent failures occurring whilst crews respond to the initial failure. As a result, live line work on copper conductor is not permitted in Victoria.

Copper has the worst condition profile of the four major material categories, as shown in Figure 12, with 75% of spans in condition rating C3. This is mainly due to Copper being the oldest material and all stranding configurations being obsolete.

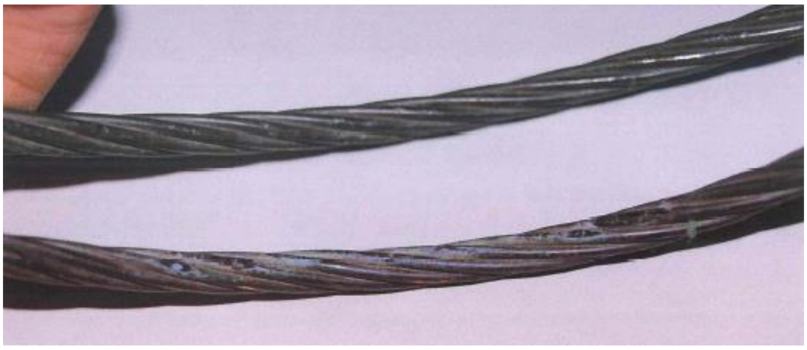

Figure 11 – Blackened Copper conductor

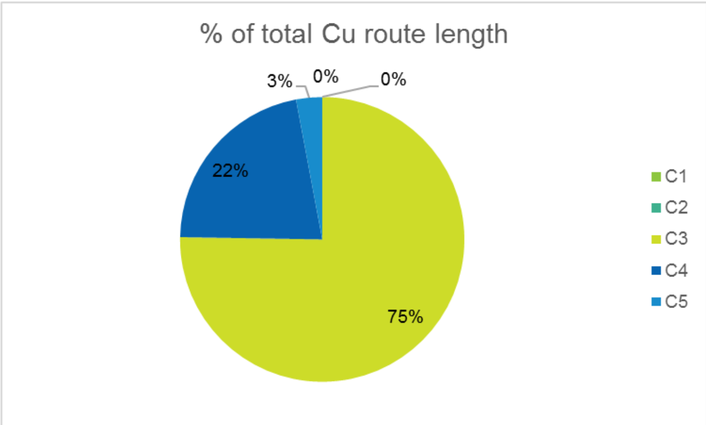

Figure 12 – Copper condition profile

The number of Copper conductor spans has diminished over the years through replacement with other materials and it now represents a small percentage of the network. Past experience outlines particular Cu conductor strandings which present the highest risk of sudden failure. These are: 7/.048, 7/.064 and 7/.073; also called “small gauge Cu”. Past proactive conductor replacement projects targeted the “small gauge” Cu as first priority.

3.4.4 Steel

Steel conductors make up the majority of the fleet covering over 58% of the network route length. It features high breaking load hence making it the preferred material type for long and very long rural spans.

The majority of steel spans are condition grade C2 as shown in Figure 13. These are mainly located in Low and Medium corrosivity area and don’t have any workorder since they were installed.

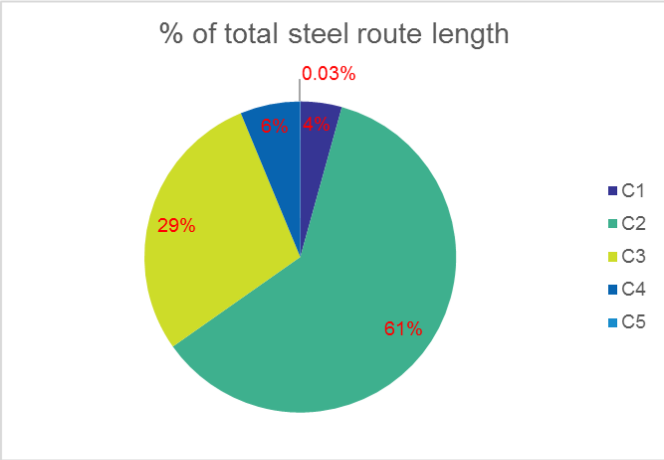

Figure 13 – Steel condition profile

The C1 score spans have been installed on the recent conductor replacement program starting 2010.

The C3 spans are located in Low & Medium corrosivity area and have a small or medium no. of Workorders since they were installed. The main driver for the C4 & C5 spans is the high no. of Workorders.

Conductor corrosion has been identified as being more prevalent in the Gippsland areas of the network, particularly along coastal areas which constitute the high and very high Corrosivity zones.

Conductor assessments performed as part of the 2011-2015 Steel conductor replacement program confirmed that proximity to the coastline accelerates deterioration of steel conductor.

Given the corrosion process pattern, in that it starts slowly by consuming the sacrificial galvanising coating and after that it accelerates with section loss it is important to continue the steel conductor replacements to prevent a situation where the volume of repacements per period is greater than it is practical to deliver over a five year period.

3.5 Asset Criticality

- The consequence of conductor system failure is allocated into five criticality bands based on their economic impact as the result of a failure. These asset criticality or consequence impacts are irrespective of the likelihood of the actual failure.
- The economic impact consists of the summation of components:

- Bushfire start impact
- Health and safety impact
- Value of unserved energy

3.5.1 Bushfire Starts

The risk associated with a bushfire is calculated by applying the probability of fire ignition, probability of unfavourable weather conditions, expected house loss consequence and house loss value. Data has been sourced from the Victorian Bushfires Royal Commission findings, Government departs, Bureau of Meteorology and CSIRO.

Fire Loss consequence model

Subsequent to a recommendation of the Powerline Bushfire Safety Taskforce, a Fire Loss Consequence Model (FLCM) was developed by Dr Kevin Tolhurst of Melbourne University. A 2km x 2km grid was placed over a map of Victoria. For each gridpoint, the model predicts the number of properties lost if a fire were to originate at that point under Ash Wednesday, no-historical, FFDI140 weather conditions. The data was then Kriged over a 5km radius. This method allowed a house loss consequence to be assigned to assets in the AusNet Services network as shown in Figure 14.

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Figure 14 - Tolhurst House Loss Consequence 2016-17 AN140 Kriged

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Figure 15 – Fire loss consequence

A Bushfire Consequence model was developed combining the FLCM, weather data from CSIRO, assumptions on FFDI (Forest fire danger index) duration and VBRC findings to derive an expected consequence for a fire started at any time as shown in Figure 15. The methodology is published in AMS CIR Quantifying Bushfire Risk Cost v2.0.docx

3.5.2 Health and Safety Impact

Health and Safety risk related, such as electric shock risk, to the possibility that a safety consequence may occur as a result of a conductor drop

3.5.3 Unserved Energy

Values of expected unserved energy were calculated by using the value of customer reliability (VCR) and the expected outage time. Mean time to restore (MTTR) is used to estimate the expected outage time. The approach taken is consistent with AEMO's energy forecasting approach as detailed in paper by AEMO and in AusNet Services Distribution Annual Planning Report (DARP)[4]

3.5.4 Overall Criticality

- The consequences of conductor system failure can be allocated into five criticality bands based on their economic impact as the result of the failure.These asset criticality or consequence impacts are irrespective of the likelihood of the actual failure.
- The five criticality bands are tabulated given in below:

Table 3 - Criticality Band

Criticality Band	Economic Impact
1	<= 0.3 consequence cost due to failure
2	0.3 to1 x consequence cost due to failure
3	1 to 3 x consequence cost due to failure
4	3 to10x consequence cost due to failure
5	>10x consequence cost due to failure

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The criticality assessment compares calculated consequence cost with replacement cost. Figure 16 offers a bare conductor fleet criticality statement. The values represent percentage of the total network route length.

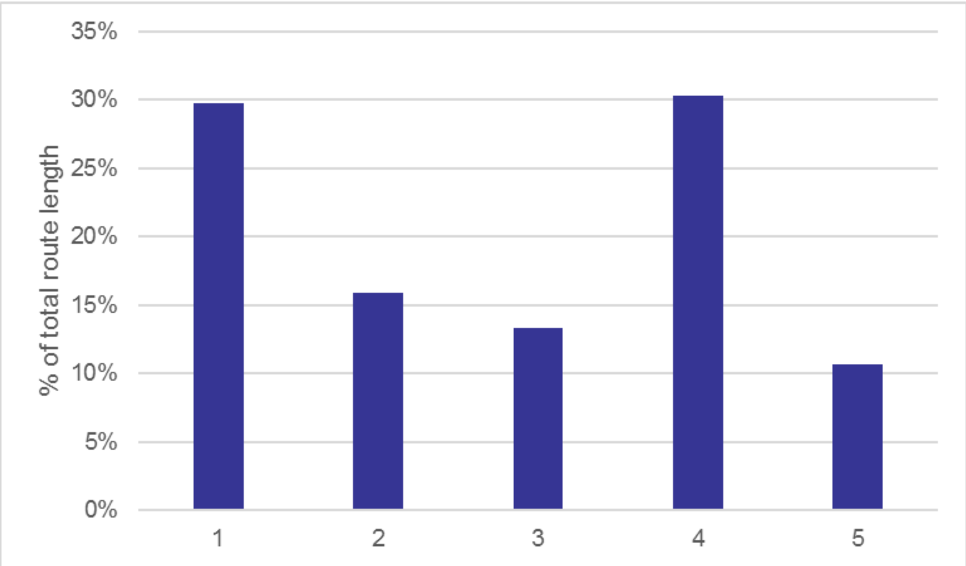

Figure 16 – Criticality Score

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[4] Distribution Annual Planning Report – AusNet Services 2018-2022

3.6 Asset Performance

Asset performance is assessed by analysing the unassisted defects and failures of the conductor systems components i.e. conductor, tie wires, D Loops, ARVD's, joints and spreaders. The analysis includes failure trend, damage cause and no. of work orders.

3.6.1 Failures

Figure 17 shows the trend of conductor and tie wire failures since 2006. Only unassisted failures (caused by corrosion, vibration and component deterioration) were considered. Assisted failures (caused by external factors such as falling vegetation, bird/animal and vehicle impacts) were excluded from the analysis. On average There were 182 conductor systems failures per year between 2006 and 2016.

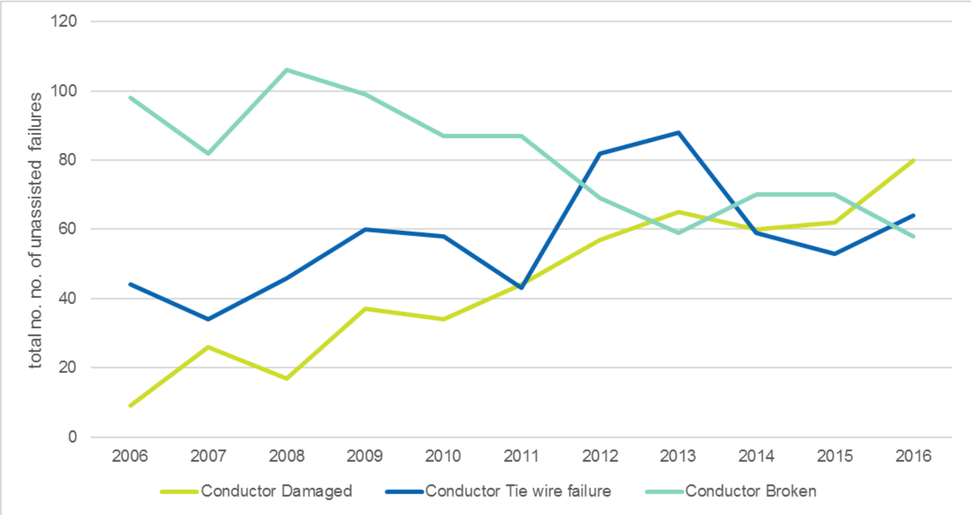

Figure 17 – Component failure trends

Figure 18 shows the overall distribution of conductor asset failures by voltage.

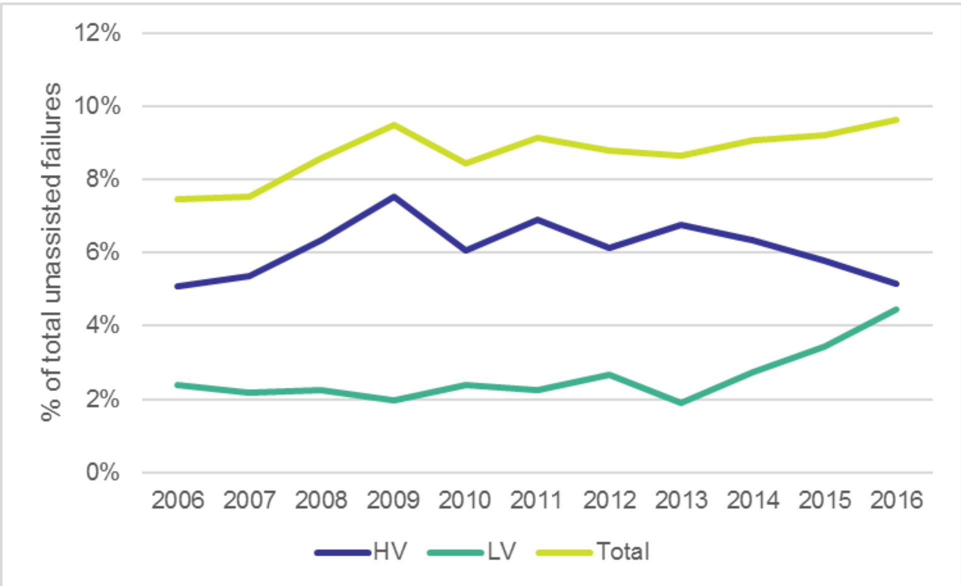

Figure 18 – Conductor unassisted failures by voltage

The conductor broken and tie wire defect down trends illustrate the efficiency of the conductor replacement program. The program focused on steel in high and medium corrosivity and high bushfire consequence areas and Cu proactive replacements while the rest of conductor materials are repaired/replaced on a BAU basis, hence the ups and downs on the trend. The tie wires are replaced as BAU as well as on the proactive ARVD, Cross-arm replacement, conductor replacement programmes.

The conductor damaged trend suggests that there is a need to continue the proactive conductor replacement program and consider the proactive replacement of sections of ACSR and Aluminium in poor condition as well in order to maintain the reliability and network safety standard.

3.6.2 Work order analysis

Work orders are generated primarily as a result of the routine asset inspection. Figure 19 shows the trend of conductor related work orders since 2006. It includes all BAU unassisted conductor systems fault types: broken strand repair, replace span, replace fittings (tie wire, ARVD, DLoop, joints and spreaders). The figure illustrates an increase in the maintenance activity starting 2010 when the safety programs started.

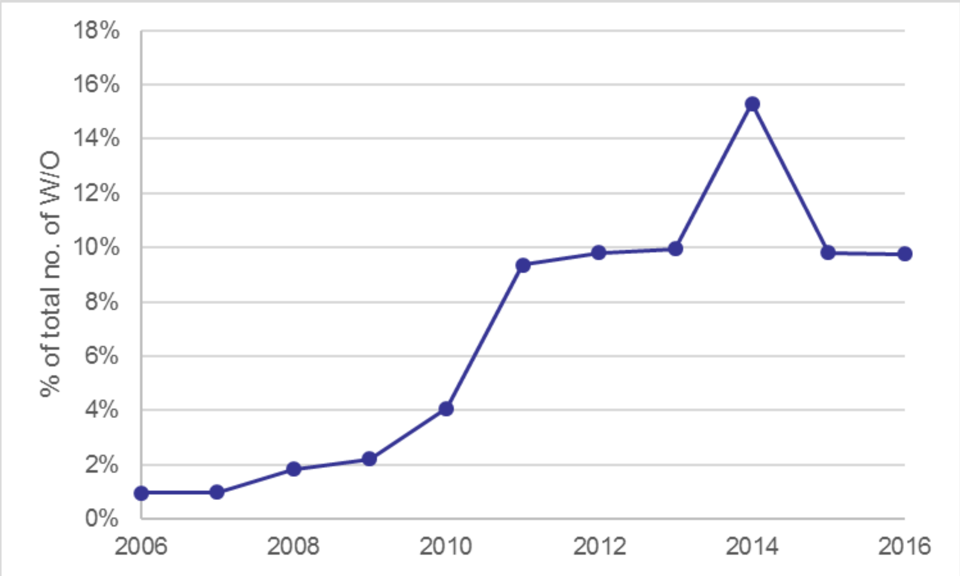

Figure 19 – Conductor systems repair workorders

Although the chart data includes the BAU workorders only and not the proactive replacement workorders the safety projects i.e. conductor replacement, ARVD, crossarm replacement, spacers provided the opportunity to identify defects since contractor crews were on site daily in addition to the inspectors. The 2014 “spike” on the characteristic is made of tie wire defects in proportion of 60% and is related to the 2010 tie wire study.

Figure 20 shows the distribution of work orders by failure code since 2006. More than half related to issues with conductor ties. This is consistent with the observation that conductor tie failures have been increasing. Deteriorated conductor accounted for 12% of the work orders.

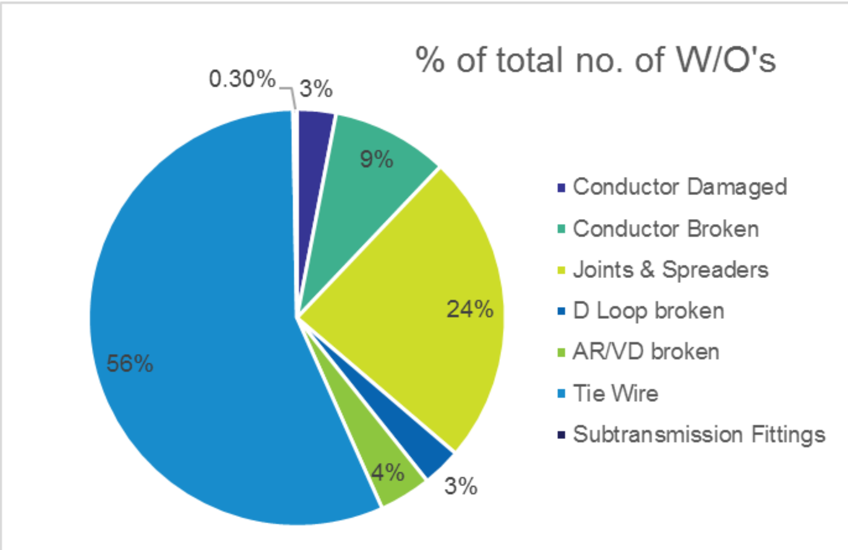

Figure 20 – Distribution of workorders by failure code

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A 2010 audit of conductor ties on AusNet Services' rural distribution network trigerred the reactuve conductor tie replacement on lines where conductor replacement was not planned for the 2011-2015 program.

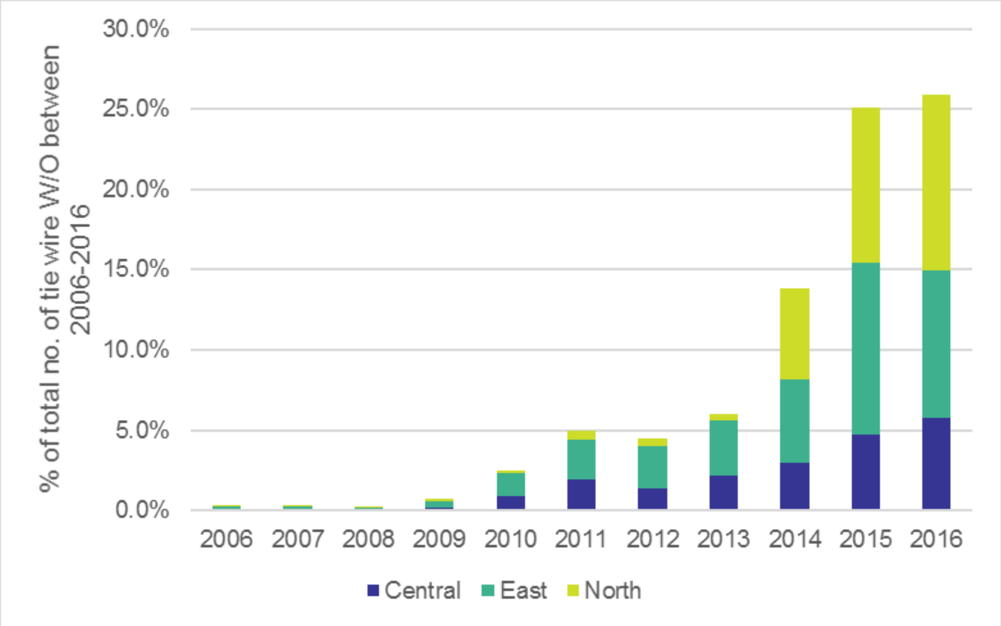


Figure 21 – Tie wire W/O trend

Conductor tie wires were replaced on the conductor replacement projects, Armour Rod and Vibration Damper (ARVD) installation, crossarms replacement in codified area as well as onand BAU maintenance activities.

Conductor tie replacement was included under maintenance activities to address network risks and concerns raised by ESV

New and replacement insulators are now of the clamp top arrangement which reduces the total number of conductor ties on the network and the need for tie replacements

3.6.3 Customer Impact

Conductor failures present the following effects or consequences:

- Network reliability – interruptions to customer supplies reflected in USAIFI and USAIDI.
- Bush fire ignition – risk of fire ignition in summer months from conductors falling in to vegetation.
- Public safety – risk of electrical shock due to conductors falling over roads or pedestrian areas.
- Compliance – failure to maintain conductor clearances to ground and buildings in accordance with accepted Electricity Safety Management Scheme.

3.6.3.1. Supply Outages

The severity of an outage is a combination of the number of affected customers and the duration of the outage.

The main reliability KPI's are the unplanned average interruption duration (USAIDI) and the unplanned system average interruption frequency (USAIFI).

Since 2010 to present , a customer experienced loss of supply due to unplanned interruptions caused by bare conductors failures in an average of 4.14 minutes per event per year as per Figure 22 This has resulted in an average of Service Target Performance Scheme (STPIS) penalty of $2.2M per year.

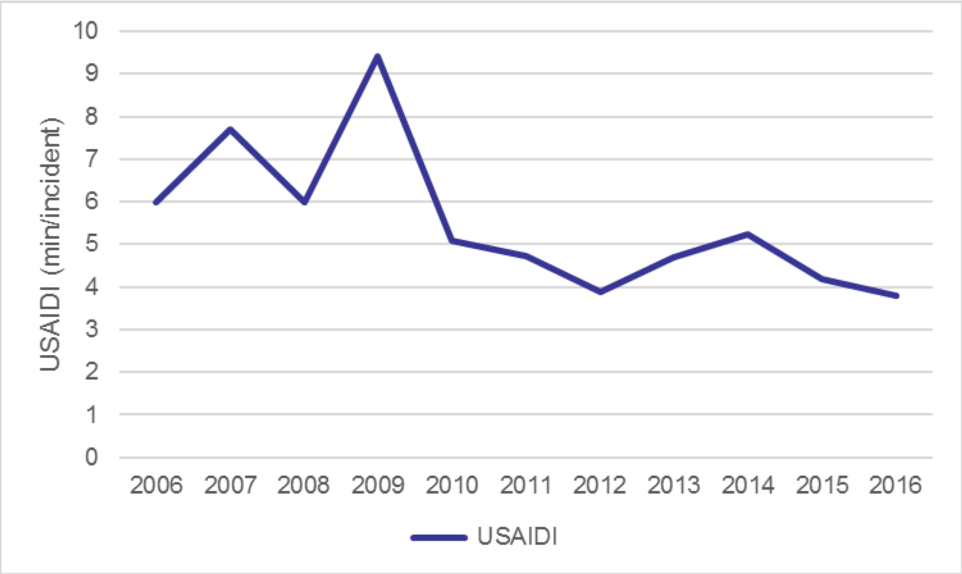


Figure 22 – Average USAIDI from conductor failures

The USAIFI Figure 23 is dropping but the number. of failures is slightly increasing trend thus the same or slightly higher number of faults results in less power interruptions. This is mainly due to the investment in the distributuion feeder automation but it also confirms the efficiency of the selection criteria for the past conductor replacement programs in limiting the number of interruptions.

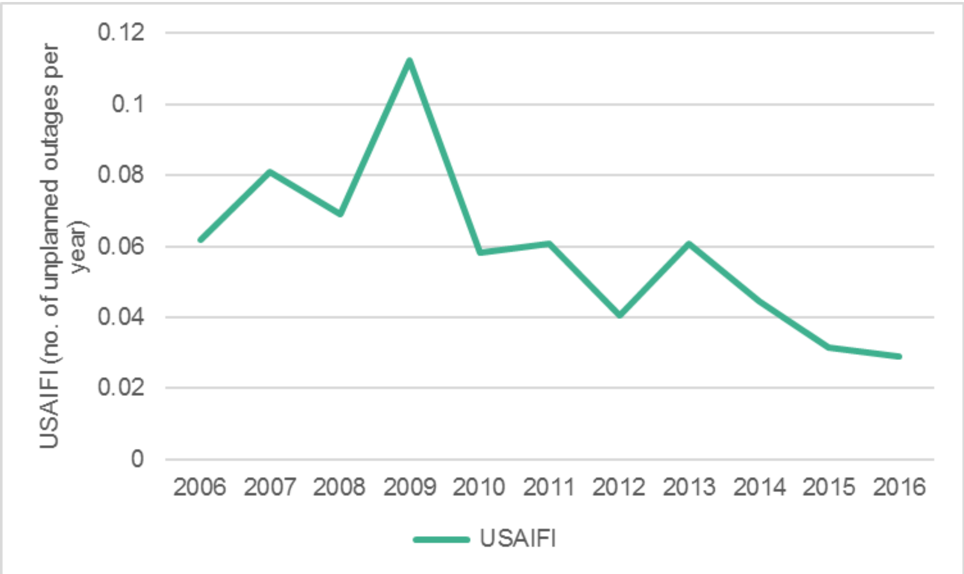
- 

Figure 23 – Average USAIFI from conductor failures per year

3.6.4 Fires

Figure 24 shows the trend of total number of ground fires at network level and conductor related ground fires from 2006 to 2017. The proportion of total ground fires caused by deteriorated conductor systems out of all ground fires started by other asset types was 17%[(4)] on average over this period. The bushfire risk is one of the main drivers for safety projects including past projects including ARVD retrofit, 56M, conductor replacement, and spacer installation.

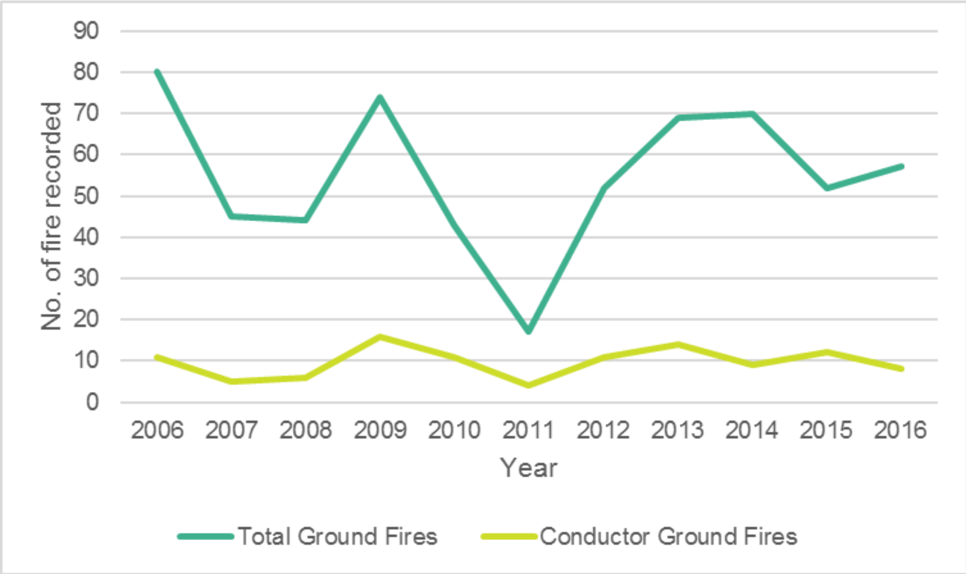


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Figure 24 – Ground fires caused by conductor defects

The most extreme consequences of fires caused by conductor failure include property damage, loss of life and loss of infrastructure. Data from the Black Saturday bushfires estimates the average cost of fire damage is $2.05M per property. The maximum asset lost consequences predicted for fires starting in the Central region are higher than 2,000 properties whilst in the Eastern region they are approximately 1,000 properties.

3.6.5 Public Safety

In addition to the dangers of bushfires, a risk to electric shock can arise through fallen or defective conductors and fittings. Electric shock incidents have decreased over the past regulatory period with the 12 month rolling average dropping from 5.8 per month in August 2014 to 3.5 per month in October 2018. The majority of electric shock incidents arise through defective service cables which are covered under AMS 20-76.

4 Other Issues

4.1 Inspection

Condition assessments are performed in accordance with the Asset Inspection Manual 0-4111.

Steel conductors are assigned a condition rating by comparing them to a standard set of photos showing conductor in various condition grades. Copper is reported when damaged or when it shows signs of blackening which may be a precursor to brittle failure. Other conductors are also assessed visually and condition status is generally reported based on signs of mechanical or corrosive damage causing loss of cross section rather than surface condition.

The current criterion are generally binary choice; damaged or undamaged. With the exception of steel, there is no graded scale of deterioration which would allow objective forecasting of future replacement rates. Visual assessment tools as well as site measurements are being investigated to promote objective measurements of deterioration. This will assist in estimating fleet condition, remaining service life and replacement requirements.

Since the previous regulatory submission, forensic analysis has been performed on 3/12 Galvanised Steel conductor which has assisted in the calculation of probabilities of failure. Condition assessment results have been calibrated against historical figures and this forensic analysis. These results have been combined with the Bushfire Consequence Model and incorporated into the optimum time for replacement model.

As an inspection methodology improvement, forensic analysis will also be undertaken on AAC and ACSR conductors. Pro-active investigation will assist in establishing objective condition assessment methodologies before an increase in conductor failures is observed on the network. Forensic analysis will assist in correlating condition with other factors such as:

- Service age
- Geographical location
- Joint and connection condition
- Vibration damage
- Electrical loading
- Fault currents
- Mechanical loading
- Lightning and weather conditions

Investment in further development of smart aerial imaging and processing (SAIP) technology is considered to provide for objective condition assessment of 66kV ACSR conductors. Such methods need to be developed before an increase in failures is seen and will be most applicable in rural sub-transmission networks.

4.2 Compliance

A range of regulatory requirements apply to conductor with regard to clearance to ground and to buildings. Where conductor assets are non-compliant with these requirements the risk of phase to phase or phase to ground fault is increased. The possible effects of low clearance conductor include electric shock and fire ignition.

AusNet Services must also comply with directives issued by ESV, the Electricity Safety Act 1998 and Electricity Safety (Management) Regulations 2009. One requirement is to submit an Electricity Safety Management Scheme, explaining how a distribution company will operate its network safelly. The Conductor Replacement program, Armour Rod and Vibration Damper program and Aerial Spacer Survey program, are examples of projects developed under this scheme in order to achieve compliance.

A recent directive requires conductor replacements in Codified areas to be made with covered conductors or underground cables.

4.3 REFCL

In line with the Victorian Electrical Safety (Bushfire Mitigation) Amendment Regulations 2016 AusNet Services is required to install the Rapid Earth Fault Current Limiter (REFCL) at specific sites. The installation and application of REFCL technology are governed by two key legislations:

i. Electricity Safety (Bushfire Mitigation) Regulations 2013;

ii. Electricity Safety Act 1998

With the introduction of REFCL's on designated zone substations there is a requirement to perform network capacitance to earth balancing. The key aspects of network capacitance to earth balancing involving bare conductors are:

- Offsetting the large capacitive imbalance on single phase spurs,
- Phasing data integrity – aquirind phasing information for each electrical section,
- Conductor construction specification – update the "unknown" conductor specifications in SAP,
- Reconductoring sections which exceed the 100mA threshold of stranding imbalance,

In order to achieve REFCL compliancy a number strategies are employed. The strategies involving overhead bare conductors are:

- All REFCL overhead feeder future constructions will be three phase capacitive balanced,
- Phase rotations used to offset single phase spurs against each other,
- Adding a third phase conductor to existing single phase spurs.

REFCL policy is covered in more detail by REF-30-06 and REF-30-09.

4.4 Emerging Capacity

An emerging issue impacting the LV distribution network is the residential customer emerging capacity through installation of rooftop PV panels and potentially in the future the increase of electric vehicles. Due to increased electricity flow on the LV network on some feeders augmentation works may be required including the LV reconductoring to increase capacity. Following the current trend the LV network importance in the distribution network will increase. This will increase the required upgrades and maintenance of the LV network.

5 Risk and Options Analysis

5.1 Overview

A conductor failure is defined as a loss of any of the electrical or mechanical functions of the conductor systems and can result from several different failure mechanisms. This risk assessment considers the following main failure mechanisms: corrosion, fatigue and vibration which lead to broken strands and then to broken conductor i.e. conductor failure. Different failure mechanisms can lead to conductor failure in a different interval of time i.e. one broken strand develops into multiple broken strands followed by conductor failure or an environment action is of such a magnitude that leads to sudden conductor failure.

An unassisted failure generally occurs when the design is not perfectly aligned with the environment actions/forces resulting in a conductor that fails instantly i.e. wind induced vibration/fatigue. In the assisted failure context there are environment actions which cannot be cost effectively mitigated through design i.e. tree falling, lightning strike, fauna impact, acts of vandalism.

The risk assessment in this submission focuses on the analysis of the unassisted failure mechanisms which develop into a fault over time. Section 6 provides asset management improvement suggestions to enable an even more accurate forecast of the conductor failure.

5.2 Risk assessment methodology

In summary the risk assessment methodology considers the following for each conductor span:

Probability of failure:

- expected life of the asset in different corrosivity zones,
- calculate remaining service potential based on current conductor condition score,
- calculate probability of failure.

Consequence of failure:

- bushfire risk cost,
- value of unserved energy - product of VCR (value of customer reliability), EAR (energy at risk) and the MTTR (mean time to repair)
- safety risk cost

Cost of replacement:

- cost of replacement in today's $ value,
- cost of replacement NPV for each option considered,
- cumulated consequence and cost of replacement NPV for each option.

Benefit of replacement:

- calculated benefit NPV as a difference between the consequence NPV and cost of replacement NPV,
- calculated preffered option as a maximum NPV benefit across all considered options.

The volumes for the proactive component of the conductor replacement program were calculated using a comphrehensive quantitative risk assessment.

Each conductor span is assigned a condition score as outlined in AHR 20-52.

A study of 195 steel conductor failures and 40 copper conductor failures was conducted and the shape parameter β and scale parameter η were calculated for each corrosivity area.

The spans are grouped by condition score and by corrosivity area. A remaining service potential (RSP%) as percentage of the expected life (useful life or η) is assigned to each condition score group of spans.

A risk model was built in Isograph AWB to calculate the probability of failure associated with each combination of the conductor condition score and corrosivity area.

Starting from the 235 failures the results are extrapolated to the entire network. The probability of failure is calibrated using the actual number of conductor failures across the entire network from SAP.

5.3 Options Analysis

The model includes 15 replacement options, calculating the risk over 55 years. For each conductor span and replacement option, the net present value (NPV) is calculated as a difference between the PV cost of replacement and PV consequence of failuret. The optimum time (year) of replacement is the option with the maximum NPV.

Figure 25 presents the model calculation output.The calculation suggests it is optimum to replace 3.5% of the network route length between 2021 and 2025.

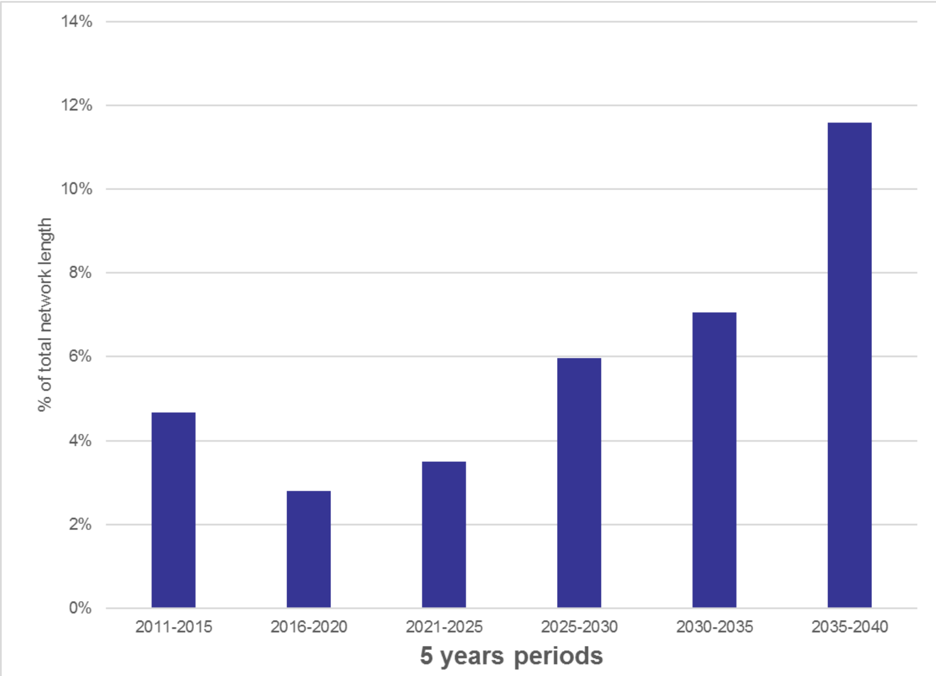

Figure 25 – Conductor Replacements, actual and forecast

In order to mitigate the highest risk the strategy is to proactively replace approx. 3.5% of the network route length or 1,292 km. Following the previous years trend, the reactive conductor replacement is estimated to 62km over the 2021-2025 period.

The rationale behind the down-trending of the volume of replacements across 2012 to 2020 period and the increase in the volume of replacements for the following period lies in the risk assessment methodology used.

In previous risk cost calculations, the bushfire ignition risk was based solely on the worst weather conditions, AN140 (corresponding to a Forest Fire Danger Index (FFDI) of 140). However, in areas where an AN140 scenario is unlikely, this resulted in a low risk cost, ignoring the risks present at lower levels of FFDI. This revised methodology uses a 3 Rectangle method of evaluation to account for the risk present at FFDI levels of 70 and 100 and represents a more accurate estimate of both the absolute and relative risk values.

The current risk assessment methodology compares risk with cost of replacement and recommends an optimum time of replacement. By contrast, the previous methodolgy targeted replacements in the high consequence areas of the network and did not consider the risk cost versus replacement cost ratio in other parts of the network. This resulted in a drop in volumes as replacements in the high consequence areas were completed, but did not address risk in lower consequence areas

5.4 Summary forecast

The FY21-25 program includes the replacement of 1,354route km of distribution bare overhead conductor systems . This includes proactive replacement of 1,292 km and reactive replacement of 62km of conductor over the period.

Table 4 - Summary of Replacement Forecast

Identifier	Justification	Contribution per Annum [km]
Proactive replacement	Risk Based replacement from condition assessment	258
Reactive Replacement	Replacement due to damage (based on historic replacement rates)	12.4
Total		270

6 Strategies

The following strategies shall be used to manage risks associated with conductors, line ties, conductor joints, armour rods, vibration dampers and spacers.

6.1 New Assets

- Utilise LV ABC cable systems for all new aerial LV circuits constructions.
- Utilise insulated underground cable, HV ABC or covered conductor cable systems for new MV circuits in codified areas.
- Utilise underground cable, HV ABC or covered conductor cable systems for new MV circuits in high Fire Loss Consequence areas on a case by case basis.
- Utilise AAC and ACSR bare conductors for new aerial MV circuits in low bush fire risk areas and in low Fire Loss Consequence areas.
- Utilise AAC and ACSR bare conductors for new aerial 66 kV circuits.
- Install armour rods and vibration dampers in accordance with AusNet Services' published technical standards.
- Utilise clamp top insulators and armour rods for all new construction.
- All new REFCL feeder overhead conductors will be three phase capacitive balanced.

6.2 Inspection

- Assess conductor, conductor tie, conductor joints, armour rods, vibration dampers and conductor spacer condition in accordance with the criteria established in the Asset Inspection Manual, 30-4111.
- Continually assess the condition of all bare conductors and maintain accurate condition status in the Asset Management Information System.

6.3 Maintenance

In conjunction with other maintenance works:

- Replace McIntyre and Fargo sleeves (if any left) with compression sleeves and helical splices.
- Replace PG clamps on HV circuits (if any left) with Wedge type connectors.
- Replace LV spreaders on LV spans in high bush fire risk areas in accordance with AusNet Services' standard VX9/7020/150.
- Replace deteriorated line ties in accordance with the criteria established in the Asset Inspection Manual 30-4111.

6.4 Replacement

- Replace deteriorated assets in accordance with the criteria established in the Asset Inspection Manual
- Replace deteriorated MV bare conductors circuits in codified areas with underground cable, HV ABC or covered conductor cable systems.
- Replace deteriorated MV bare conductors circuits in high Fire Loss Consequence areas with HV ABC or covered conductor cable systems on a case by case basis.
- Replace deteriorated MV bare conductors in LBRA and in low Fire Loss Consequence areas with AAC and ACSR bare conductor.
- Replace deteriorated 66 kV bare conductors with AAC and ACSR bare conductors.

- Proactively replace approximately 1,292 km route length of poor condition conductor between 2021 to 2025 to manage bushfire ignition risk, conditional asset failures and mitigate reliability impacts.

6.5 Research and Development

- Research, develop and implement objective condition assessment criteria, based on forensic analysis, for AAC and ACSR conductors.
- Consider using SAIP technology to inspect 66 kV conductors supported by sub transmission towers.
- Improve steel conductor condition inspection in line with current industry practices.