AMS 10-79 Transmission Line Conductors and Ground Wires

2023-27 Transmission Revenue Reset

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Table of Contents

1 EXECUTIVE SUMMARY

This document defines the asset management strategies for the Victorian electricity transmission network's population of conductor and ground wire to maintain the safety, quality and security of supply.

The fleet of transmission line conductors and ground wires are ageing. Approximately 55 per cent of the population has been in service for more than 50 years, this figure will increase to 60 per cent by 2025. Although conductor and ground wire assets are ageing, primary inspection techniques indicate that they are generally in good condition, however some assets are showing signs of corrosion-based deterioration. Corrosion is most prevalent in areas exposed to coastal or industrial pollution.

High level strategies to be adopted for prudent and efficient management of the transmission line conductor and ground wire fleet are:

1.1 New Assets

- All newly installed conductors are designed and constructed in accordance with current industry guidelines and standards[1].
- Replace ground wires with OPGW where required for communication purposes.
- Install AAAC in area subjected to extreme corrosivity to ensure maximum life. AAAC is more corrosion resistant than ACSR.

1.2 Inspection

- Continue improving the Smart Aerial Image Processing (SAIP) technology to assess the condition of conductor and ground wire systems. A program of inspection involving a full coverage over a 3-year period followed by a reduced ongoing program to cover 50% in each following 3-year period is recommended.
- Introduce an inspection program in terminal stations.
- Continue improving the existing transmission line inspection regime as outlined in LPP 09-01 and LPP 09-06.

1.3 Maintenance

- Replace or repair defective conductor and ground wire assets as part of corrective maintenance tasks.
- Manage the transmission line ground clearance in line with AMS 10-75-21.

1.4 Replacement

- Replace 100 span of phase conductors by 2027
- Replace 979 ground wire spans by 2027
- Coordinate the ground wire replacements based on condition with those based on telecommunication upgrades.

[1] AS/NZS 7000:2010 Overhead Line Design – Detailed Procedures.

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 transmission line conductors and ground wires installed in in AusNet Services' Victorian electricity transmission network. 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 AusNet Services' 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

This asset management strategy applies to the following regulated assets within the Victorian electricity transmission network operating at voltage of 66 kV and above:

- Transmission lines conductors;
- Transmission line ground wire (including optical fibre ground wire);
- Terminal station ground wires; and
- Associated fittings.

Phase conductors included in the scope are from the start terminal station rack to the end terminal station rack on each circuit.

The strategies in this document are limited to maintaining installed capability in terms of equipment performance and rating. Improvements in quality or capacity of supply are not included in the scope of this document.

2.3 Asset Management Objectives

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

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

As stated in *AMS 10-01 Asset Management Strategy -Transmission Network*,, the electricity transmission network objectives are:

- Maintain top quartile benchmarking;
- Maintain reliability;
- Minimise market impact;
- Maximise network capability;
- Leverage advances in technology and data analytics;
- Minimise explosive failure risk.

3 ASSET DESCRIPTION

3.1 Asset Function

3.1.1 Phase Conductors

The primary function of phase conductors is to safely and efficiently transmit electrical energy between terminal stations. There are three different types of phase conductors in use on the transmission network including aluminium conductor steel reinforced (ACSR), All Aluminium Conductor (AAC) and all aluminium alloy conductor (AAAC). All conductors are manufactured and tested in accordance with the relevant standards[2,3].

3.1.2 Ground Wires

There are three different types of ground wires (GW) in use on the transmission network:

- Steel;
- ACSR; and
- Optical fibre ground wire (OPGW).

Traditional ground wires perform two key functions:

- Shielding phase conductors from lightning strike and
- Reducing voltage rise at structures by providing multiple paths for fault currents.

OPGW offers additional functionality by providing communication links between terminal stations.

3.2 Asset Population

3.2.1 Phase Conductors

Phase conductors operate at five standard voltages including 500 kV, 330 kV, 275 kV, 220 kV and 66 kV.

A phase conductor system can be a single conductor or a bundle of multiple sub-conductors (double, triple or quadruple). Phase conductor lengths are reported as circuit route length, which counts all three phases on an individual circuit as one asset.

The total route length of EHV and HV phase conductor on the transmission network exceeds 6,500 km, consisting of over 17,300 circuit spans (as of November 2019).

Conductor gauge sizes vary depending on the electrical and mechanical design requirements for each transmission line. For simplicity of identification most conductors are given code names. The most common conductor types on the transmission network are ACSR. Parts of the network are gradually replaced with Aluminium conductors.

Figure 1 displays conductor route length by voltage and type as a percentage of the total conductor population. The 220kV network represents 61 per cent of the total route length and is served by ACSR conductor. The combined route length of Aluminium conductors contributes less than 1 per cent of the total network span length.

[2] AS/NZS 3607.1989 Conductors – Bare Overhead – Aluminium and aluminium alloy – Steel reinforced.

[3] AS/NZS 1531.1991 Conductors – Bare Overhead – Aluminium and aluminium alloy.

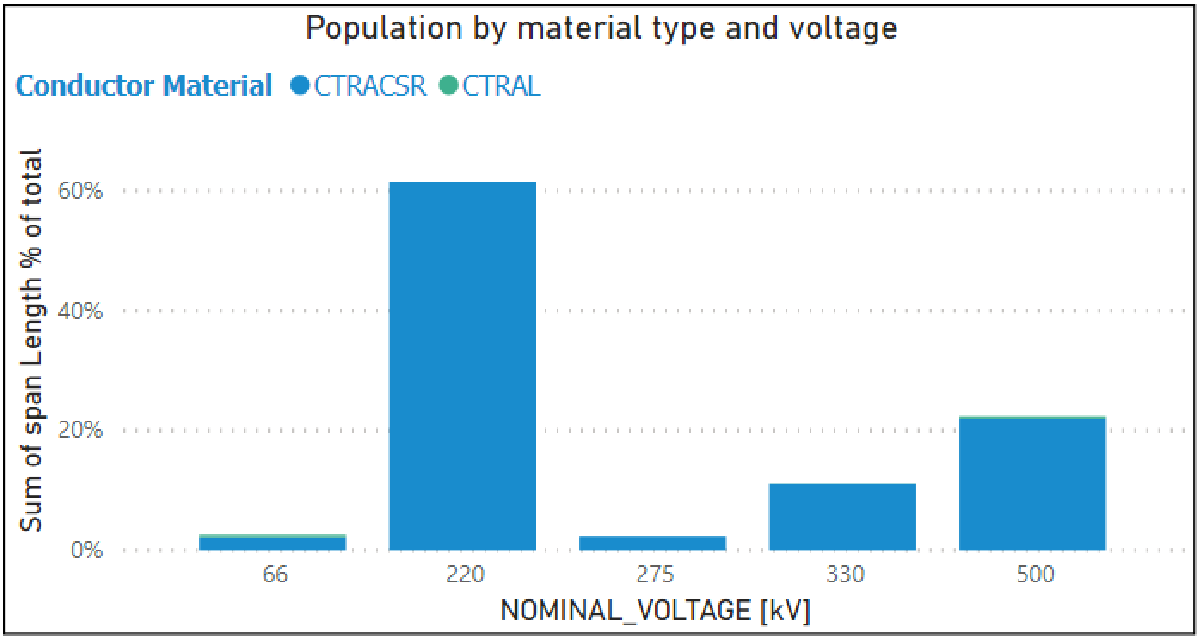

Figure 1: Conductor Route Length by voltage and material type

3.2.2 Conductor fittings and hardware

Fittings and hardware provide mechanical links between conductors and other transmission line assets. Conductor spacers provide stability to bundled phase conductors.

Conductor fittings include:

- Vibration dampers;
- Fittings and hardware; and
- Conductor spacers.

Vibration dampers are fitted to most conductors and some ground wire to minimise the effects of wind induced aeolian vibration.

AusNet Services' engineering management software SAP does not capture these as individual assets however they are referred together with the conductors as the conductor systems.

3.2.3 Ground Wires

EHV conductors and some HV conductors are shielded from lightning strike by approximately 7,400 km of ground wire and OPGW positioned above phase conductors on the line structures, consisting of over 19,300 circuit spans (as at November 2019).

Additionally, there are approximately 917 ground wire spans providing for lightning strike protection in terminal stations.

Each span of ground wire is counted as a separate asset, hence on towers featuring multiple ground wires, each span of ground wire is counted as an individual asset.

The ground wire route length by voltage and type is shown in Figure 2.

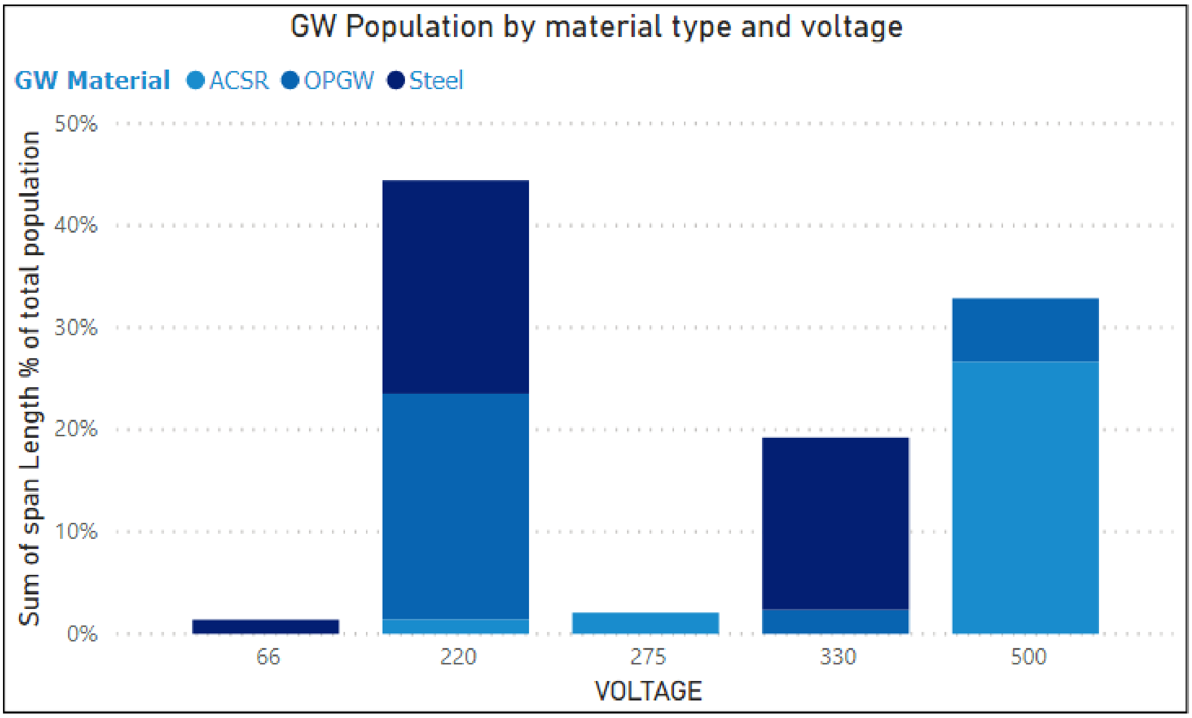

Figure 2: Ground wire Route Length by voltage and material type

The 220 kV network has over 40 per cent of the ground wire route length as it contains the highest number of double circuit towers[4].

The 500 kV and 330 kV networks contain a higher proportion of single circuit towers which contain two ground wires per circuit. This explains the more even distribution of ground wire lengths across voltage classes when compared to the conductor population.

3.3 Asset Age Profile

The Victorian transmission network initially consisted of 220 kV lines built to connect Melbourne and the larger regional cities of the state to generators in the Latrobe Valley. Construction of 220 kV lines first began in 1950.

Connections to the New South Wales network were later achieved via 330 kV lines built between the late 1950s and early 1980s.

The 500 kV lines from the Latrobe Valley to Melbourne provided further capacity to meet demand growth and to support heavy industry in South West Victoria.

The 275kV lines were built from Heywood in 1988 to provide connection with South Australia and the 66kV lines were first built in 1924 connecting the Latrobe Valley with East Rowville terminal, followed by 1972 and 1981 network extension.

Figure 3 shows the service age of the transmission line conductor population by operating voltage as a percentage of the total conductor route length of 6,500 km.

Approximately 55 per cent of the conductor fleet has been in service for more than 50 years and is expected that this will increase to 60 per cent by 2025.

[4] AMS 10-77 Transmission Line Structures.

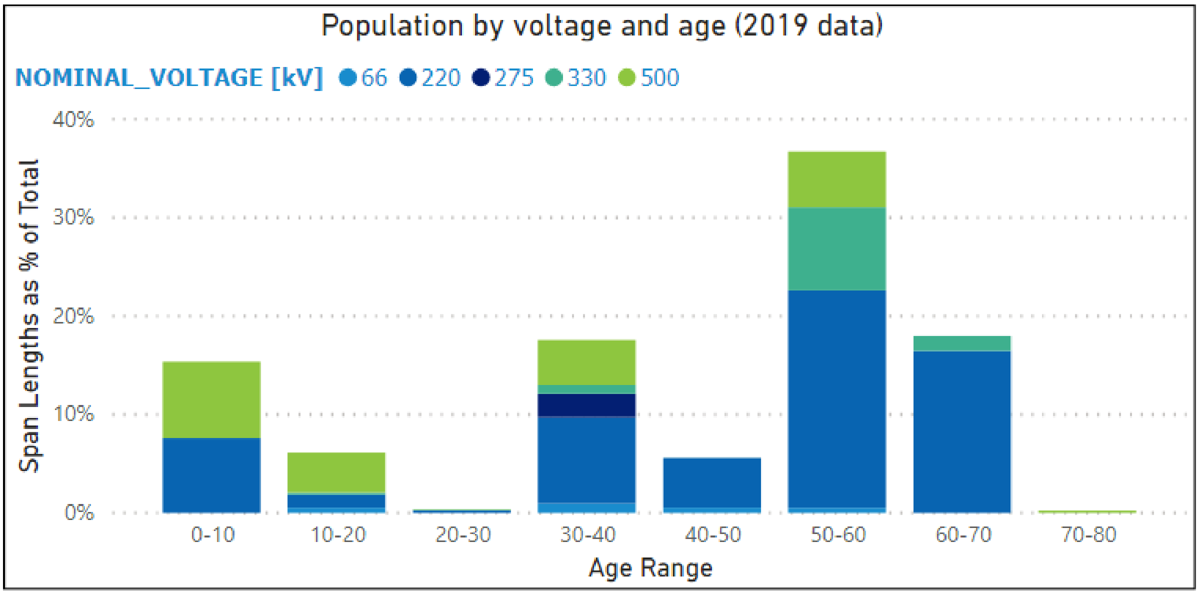

Figure 3: **Conductor service age profile by voltage**

Figure 4 shows the service age of the transmission line ground wire population by operating voltage as a percentage of the total ground wire route length of 7,400 km.

Approximately 43 per cent of the ground wire fleet has been in service for more than 50 years and is expected that this will increase to approximately 45 per cent by 2025.

The average age of ground wire is highest on the 220 kV and 330 kV networks respectively.

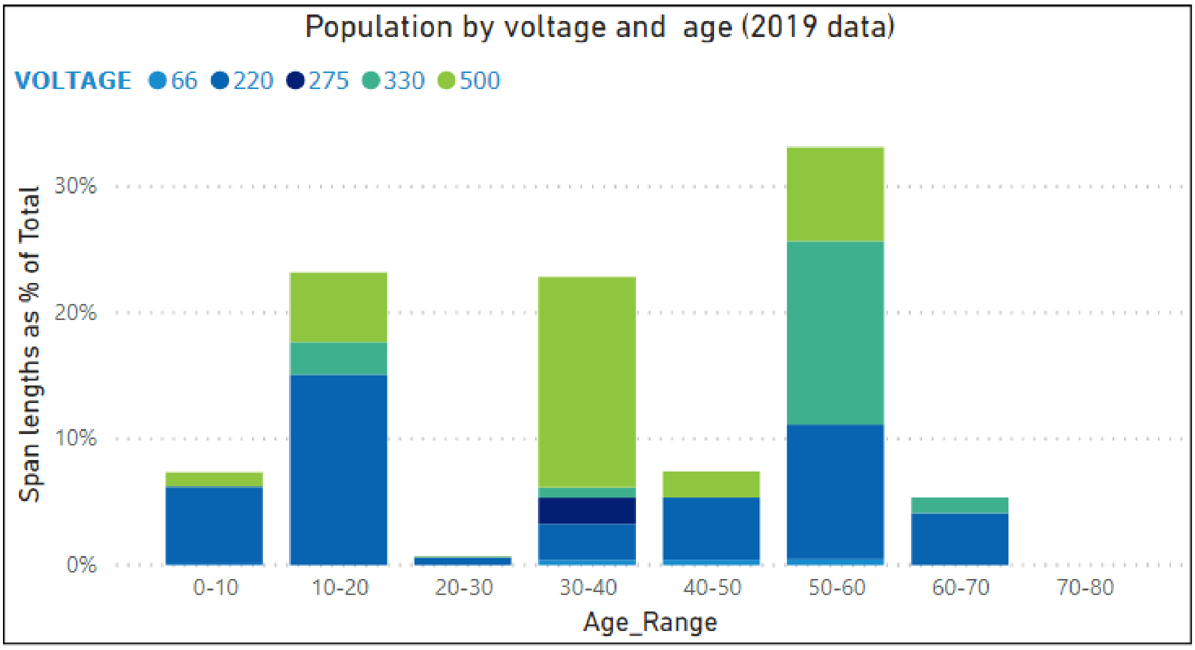

Figure 4: Ground wire service age profile by voltage

AusNet Services has implemented extensive ground wire replacement programs over the last two decades.

Replacement programs have been primarily driven by the need to upgrade the network's communications systems to meet the performance specifications of the National Electricity Market.

Communication upgrades resulted in the replacement of 30 per cent of ground wire with OPGW. Steel and ACSR ground wire make up the remaining 40 per cent and 30 per cent respectively of the total ground wire route length. Approximately 5 per cent of the network Steel and ACSR ground wire was replaced like for like due to poor condition while the remainder is generally in service since the line was originally built.

3.4 Asset Condition

The condition of the conductor and ground wire can be summarised in following table:

Table 1 – Condition Score

Condition Score	Condition Description	Summary of Condition Score Main Characteristics	Recommended Action
C1	Very good service	Conductors are generally new and in very good operating condition with no past history of significant defects or failures. No action is required for these conductors.	No action required.
C2	Better than average service	Conductors are in better than average service condition. They require routine maintenance and condition monitoring to prevent failures occurring.	Routine maintenance and condition monitoring.
C3	Average	Conductors are in average service condition. They require routine maintenance and condition monitoring to prevent failures occurring.	Routine maintenance and condition monitoring. mid
C4	Poor service	Conductors are in poor service condition. They require routine maintenance and condition monitoring and may require broken strand repair.	Less than 22% remaining life
C5	Very poor service	Conductors are in very poor service condition. They require routine maintenance and condition monitoring and may require broken strand repair. Expect conductors require replacement with 5 years.	Less than 8% remaining life

3.4.1 Condition Assessment

The condition of transmission line conductor and ground wire is primarily assessed during tower inspections which are conducted for each transmission structure. The condition data collected is used to develop asset management strategies.

Conductors and ground wires are assigned a condition grade per span on a scale between C1 (best) and C5 (worst) against specific grading parameters. The condition scoring criteria is outlined in LPP 09-01 *Inspection and Patrol of Transmission Lines*. Condition grades focus on factors which are known to adversely affect the electrical or mechanical properties of the assets including corrosion and broken strands.

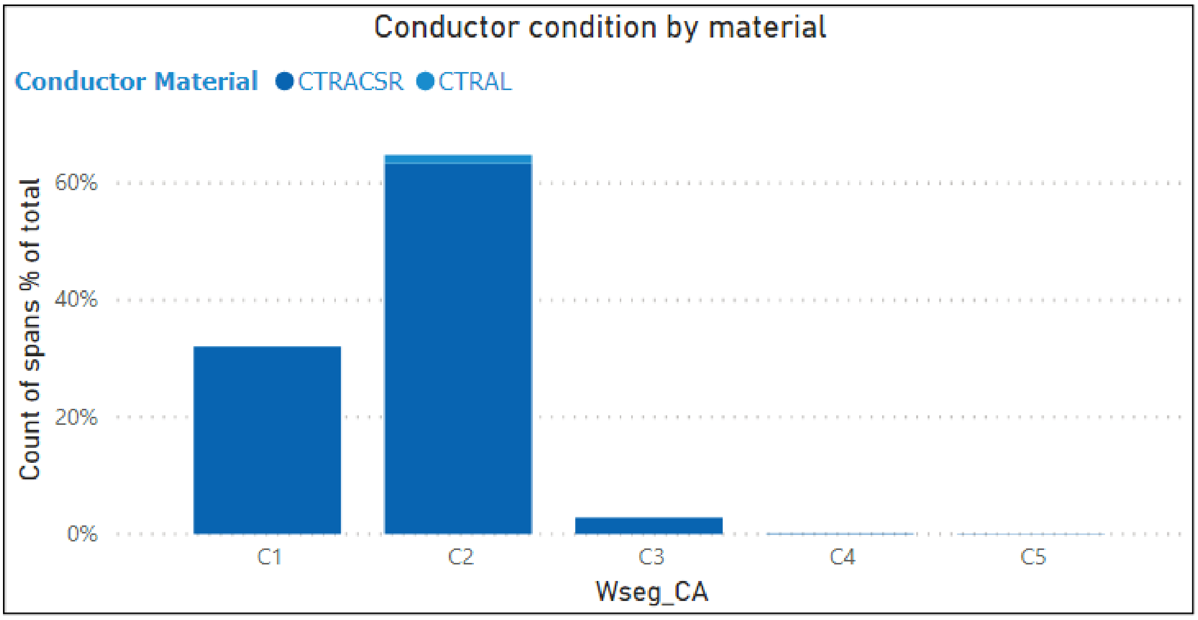

Figure 5: Conductor by condition scores

Figure 5 features a small volume of 0.25% of total span population in condition C4 and C5. Conductors in C1 include recent conductor replacements in high corrosivity area. Conductors in C2 amount to 65 per cent of total span population. This is representative for majority of the network and is in low corrosivity environment.

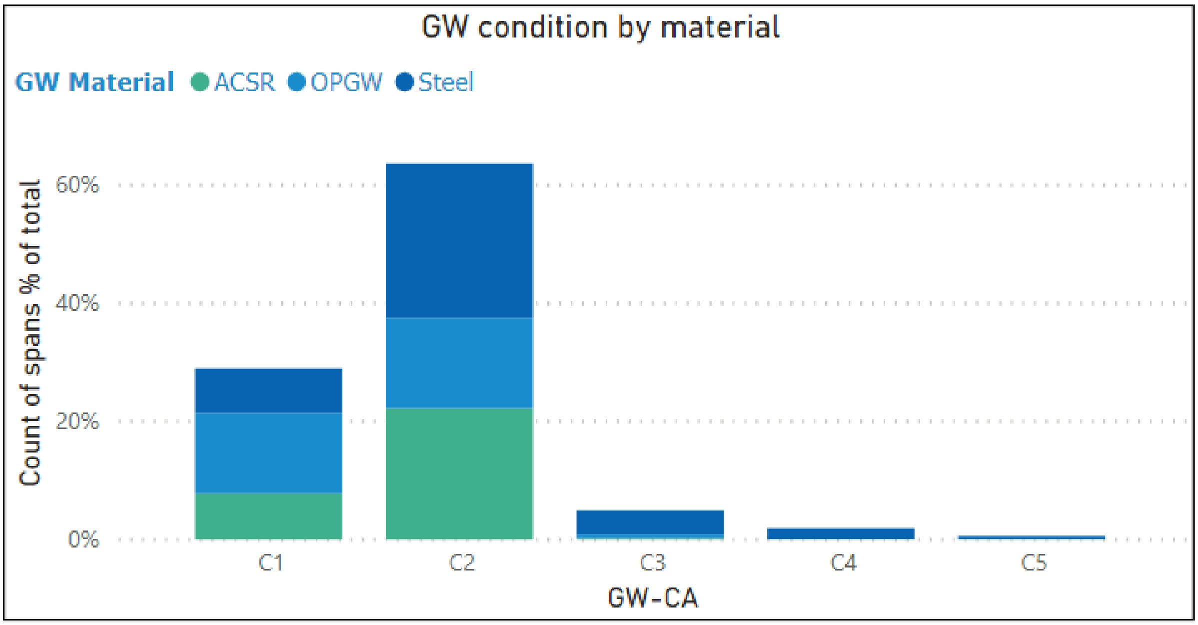

Figure 6: Ground wire by condition score

Figure 6 features a volume of 2.35% of total spans population in condition C4 and C5. This is greater than the conductor volume in C4 and C5 due to ground wires having a smaller cross section and being impacted more readily by corrosion.

Ground wires in C1 include recent replacements in high corrosivity area and on communication projects. Conductors in C2 amount to 64 per cent of total span population. This is representative for majority of the network which is low corrosivity environment.

Station ground wires are in better condition than the lines with less than 1% of total spans in C3 and the rest in C1 and C2.

3.4.2 Corrosivity Zones

The transmission line network is exposed to varying levels of corrosivity depending on environmental factors. The two factors which have the greatest impact on levels of corrosivity include salt deposition experienced in coastal regions and air pollution caused by emissions from heavy industry.

To manage the effects of corrosion in a prudent manner corrosivity classifications are assigned to transmission line assets.

There are three corrosivity zones (shown in Appendix B):

- including severe (zone 3);
- moderate (zone 2); and
- low (zone 1).

Figure 7 and Figure 8 feature the percentage of the total populations of transmission line conductors and ground wires respectively located in each of the three corrosivity zones by condition score. There are only approx. 65 km of conductor and ground wire route length in severe corrosivity and this have been replaced in last 10 years and is currently C2. Conductor and ground wire spans in C4 and C5 are in majority in medium corrosivity zone with 0.25% of total conductor span population in C4 and C5 and 2.35% of total ground wire spans population in condition C4 and C5.

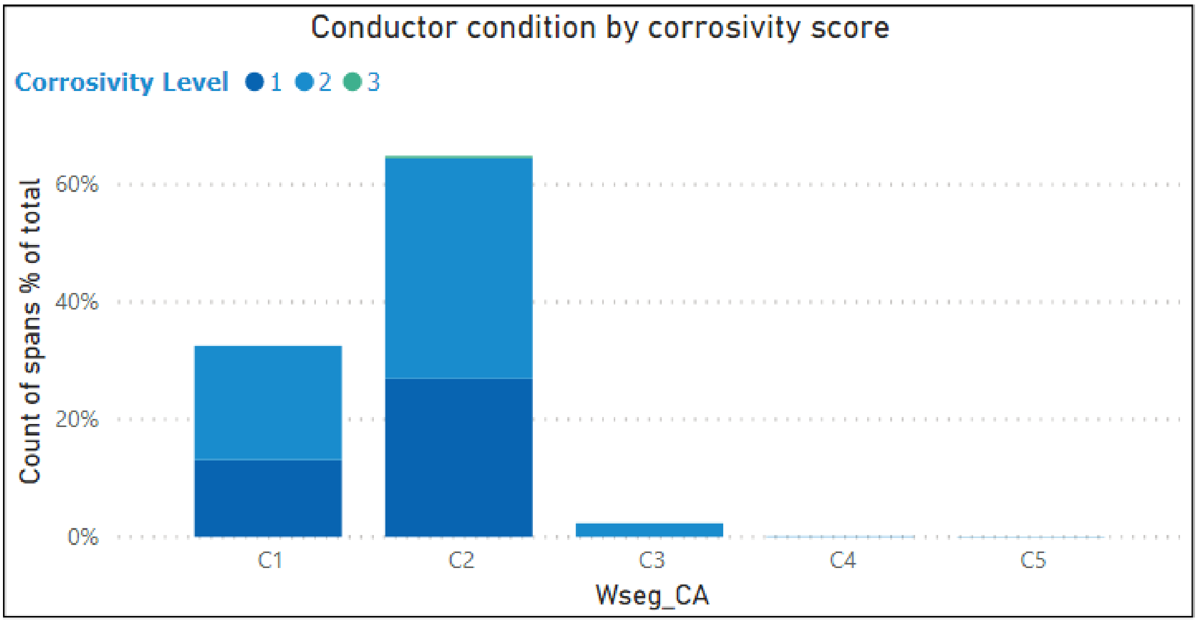

Figure 7: Conductor by corrosivity zone

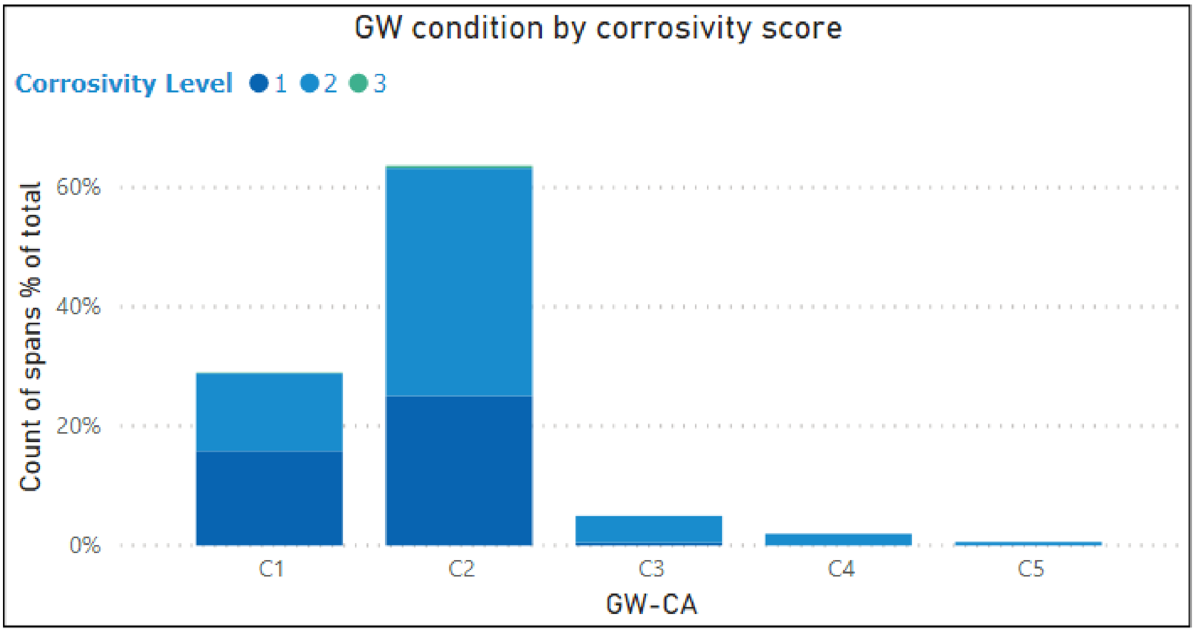

Figure 8: Ground wire by corrosivity zone

3.4.3 Smart Aerial Image Processing (SAIP)

An improved visual inspection technique, known as SAIP, was introduced in 2015 and has now been established as a routine inspection activity in 2020.

The SAIP system includes capture of continuous high-resolution conductor images from a helicopter and the use of automatic image recognition technology to locate and prioritise repair and replacement of conductor damage.

This technology enables the efficient capture of conductor images spanning long distances of transmission lines. Images captured are analysed using machine learning software which aims to automate the identification of signs of corrosion including the presence of white powder, conductor bulging or broken strands.

An automatic defect identification algorithm for conductors and associated fittings is under development.

3.5 Asset Performance

AusNet Services uses Failure Mode Effect and Criticality Analysis (FMECA) to identify modes and causes of failure for the conductor and ground wire fleet.

FMECA is the foundation for the development of effective Reliability Centred Maintenance (RCM) strategies.

3.5.1 Suspended Failures

Suspended failures are defects that are detected and repaired before they cause a functional failure (i.e. outage).

AusNet Services line inspection program is outlined in LPP 09-01 and LPP 09-06 *Condition Assessment of Overhead Lines*. The inspection program is aimed at objectively assessing the condition of transmission line components and identifying assets which are not fit to remain in service. Assets deemed not fit for service are replaced via work orders raised in Enterprise Asset Management information system.

Since 2015 there have been a total of 2,545 conductor and ground wire systems (conductor, hardware and fittings) defects, predominantly caused by the hardware and fittings as well as environmental defects like bird nest and foreign object on conductor.

Approximately 10 per cent of the defects are suspended failures. These are conductor and ground wire defects caused by corrosion and abrasion which resulted in broken strands which could have resulted in conductor or ground wire failure. A breakdown of the conductor systems parts which caused the suspended failures is presented in Figure 9 and a breakdown of the damage code is presented in Figure 10.

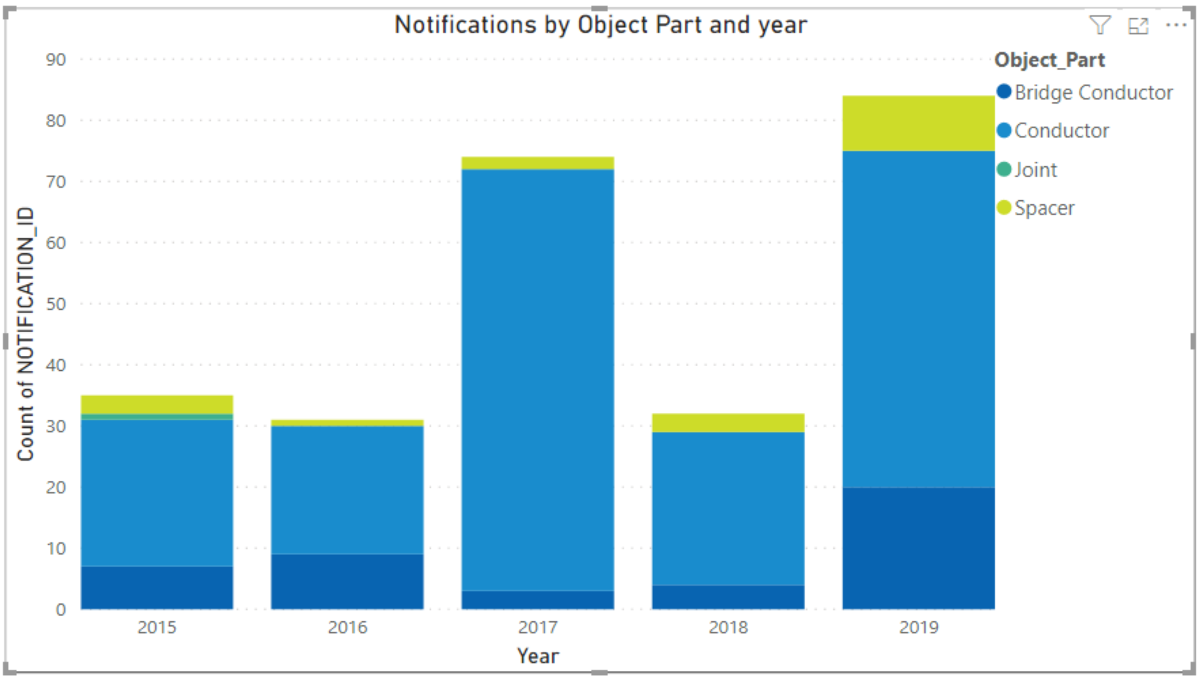

Figure 9: Conductor and GW systems suspended failures by object part and year

The increase in "conductor" object part suspended failures starting 2017 and spacer in 2019 is due to introduction of the aerial conductor inspection programme SAIP.

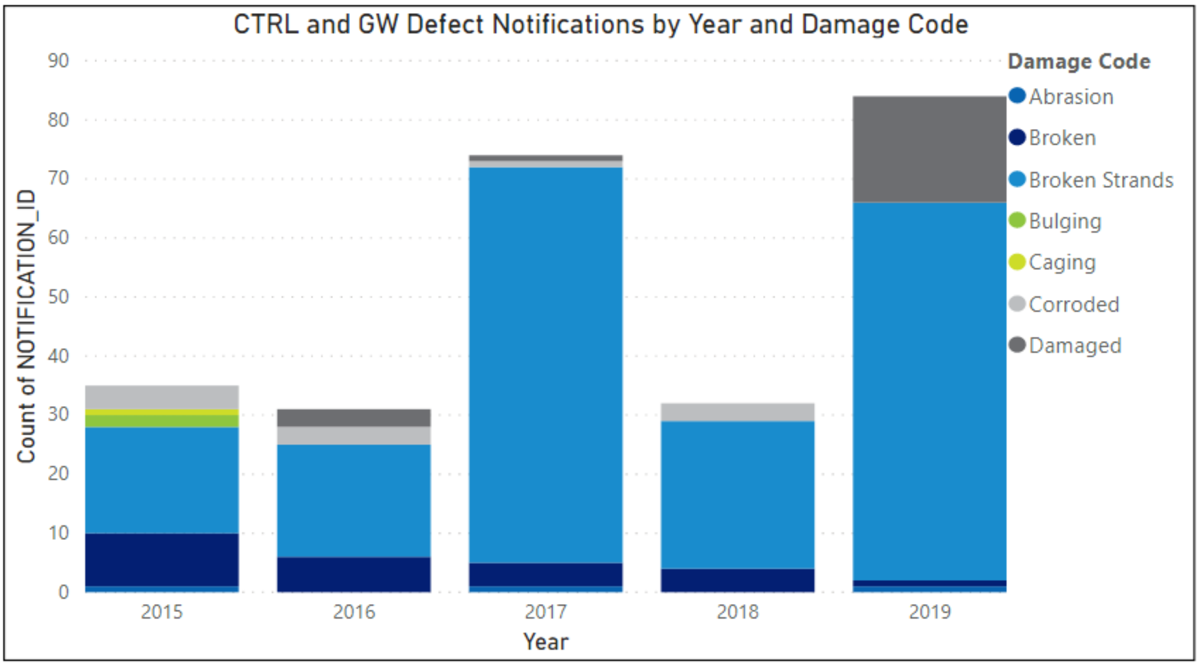

Figure 10: Conductor and GW suspended failures by damage code and year

3.5.2 Functional Failures

A conductor functional failure is an incident which prevents the safe flow of electricity. It is defined as loss of either of the electrical or mechanical functions of the conductor systems and can be caused by several different failure mechanisms.

A ground wire functional failure is an incident which renders the phase conductors unprotected against an imminent lightning strike and prevents the effective transfer of data in case of an OPGW.

Functional failures also constitute incidents which present significant health and safety risks to AusNet Services' workers and contractors and potentially members of the public depending upon location.

The majority of conductor and ground wire functional failures result in loss of mechanical function followed by loss of electrical/communication function i.e. conductor or ground wire falling to ground or onto phase conductors below.

There have been 7 incidents[5] of conductor functional failure due to condition deterioration (unassisted) over a period of 47 years as per Table 2.

[5] Conductor drop incidents due to tower collapse, installation error or manufacturing defects in conductor hardware and fittings are not included.

Table 2: Unassisted conductor functional failures

Year	Circuit Name	Number of spans and type of conductor	Damage	Cause	Environment
1972	500 kV HWTS-SMTS	1 x ACSR conductor	Broken Strands	Corrosion due to localised Industrial pollution	Paper manufacturing plant in Maryvale
1988	220 kV GTS-PTH	1 x ACSR conductor	Broken Strands	Abrasion due to vibration damper clamp	Rural, medium corrosivity
1998	220 kV RWTS-TTS	1 x ACSR conductor	Broken Strands	Corrosion due to localised Industrial pollution	Metal smelting plant in Dalton Road, Thomastown
2008	500 kV HYTS-APD	2 x ACSR conductor	Broken Strands	Corrosion due to salt deposition	Within 2 km from open ocean shore
2010	500 kV HYTS-APD	1 x ACSR conductor	Broken Strands	Corrosion due to salt deposition	Within 2 km from open ocean shore
2014	500 kV HYTS-APD	1 x ACSR conductor	Broken Strands	Corrosion due to salt deposition	Within 2 km from open ocean shore
2016	220 kV MLTS-HYTS	1 x ACSR conductor	Broken Strands	Abrasion due to defective spacer clamp	Agricultural, low corrosivity

3.5.3 Corrosion

All conductor functional failures have been caused by corrosion. All these incidents took place in areas of extreme industrial or coastal pollution where degradation of conductor condition has been accelerated.

In an open ocean High Corrosivity environment, corrosion of steel strands has resulted in reduction of ACSR conductor ultimate tensile strength and failure after just 25 years of service. In other corrosivity environments ground wires and conductors arrived at the end of serviceable life in a longer time span as outlined in the risk methodology AMS 01-09 *Asset Risk Assessment Overview*. This failure mode drives most of the proactive replacement program.

3.5.4 Vandalism, Foreign Objects and Lightning Strike

In past five years there have been over 200 incidents which have directly impacted conductor and ground wire systems. Some of these lead to assisted ground wire functional failures as featured in Table 3.

These include acts of vandalism, foreign objects and lightning strikes. Most of these incidents can be mitigated through design to a certain extent but not eliminated completely.

Table 3: Assisted ground wire functional failures

Year	Circuit Name	Number of spans and type of conductor	Damage	Cause	Environment
2002	220kV BATS-BETS	1xOPGW	Broken Strands	Lightning strike	Low corrosivity
2002	220kV BETS-SHTS	1xOPGW	Broken Strands	Lightning strike	Low corrosivity
2004	Eildon River Xing	1xOPGW	Broken Strands	Aeroplane impact	Low corrosivity
2005	220kV BLTS-MLTS	1xOPGW	Broken Strands	Lightning strike	Low corrosivity
2007	220kV MKPS-MBTS	1xOPGW	Broken Strands	Lightning strike	Low corrosivity
2011	220kV BATS-BETS	1xOPGW	Broken Strands	Lightning strike	Low corrosivity

3.6 Asset Criticality

Conductor and ground wire functional failures can result in conductors falling to the ground or onto phase conductors below and so can have significant impacts or consequences. Conductor and ground wire functional failures can lead to three main consequence types:

1. Health and safety;
2. Bushfire ignition; and
3. Market impact.

The effects of all transmission line component failures are quantified in an RCM model.

3.6.1 Health and Safety

Conductor and ground wire functional failures can present health and safety risks to members of the public, AusNet Services' employees and contractors accessing the transmission line easements.

The Health and Safety asset criticality is quantified at span level by a combination of two characteristics:

1. Easement type; and
2. Line crossings.

Transmission line easements traverse lands with various use types. Easements are classified into three easement types:

1. Urban;
2. Rural developed; and
3. Rural not-developed.

For details on health and safety consequence model of a failed conductor and ground wire see AMS 01-09.

3.6.2 Bushfire Ignition

Faults on transmission line assets can result in discharges of energy which are capable of igniting ground fires. Some transmission lines are situated in easements through high density fuel loads in grasslands and forests. In extreme weather conditions ground fires started close to such fuel loads can quickly develop into widespread bushfires.

Bushfire loss consequence modelling performed by Dr. Kevin Tolhurst[6] of Melbourne University has enabled the establishment of quantitative bushfire consequence values for transmission line assets. A map displaying the bushfire consequences associated with transmission line assets is included in Appendix C.

To date there have been no incidents of bushfire ignition from transmission line conductor or ground wire assets on the Victorian transmission network. This is mainly due to:

- Low conductor to ground faults on transmission lines and this reduces the risk of fire start,
- Transmission lines protection systems are very quick to interrupt the current flow into a fault,
- Transmission lines easements are wide and well managed, and this reduces the risk of fire spread.

3.6.3 Market Impact

The electricity transmission lines forming the National Electricity Market have high levels of redundancy under average loading conditions. However, at peak loading periods; transmission line failures can constrain generator connections causing a re-scheduling of generators in other states and load shedding may be required to provide network security for a subsequent un-related failure.

Conductor or ground wire functional failures result in system outages which negatively impact on performance levels within the incentive schemes.

For more details on market impact calculation please see AMS 01-09 *Asset Risk Assessment Overview*.

[6] A Bushfire Risk Assessment for the AusNet Services HV Network in Victoria 2014.

3.6.4 Overall Asset Criticality

The consequence of conductor system failure is allocated into five asset 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.

For a detailed asset criticality methodology see document AMS 01-09 *Asset Risk Assessment Overview*.

The Asset Criticality Score is assigned to each span by grouping the asset criticality into five asset criticality bands as per Table 4.

Table 4: Multiplier Factor and Asset Criticality Score

Asset Criticality Band	Economic Impact
1	<= 0.3 x replacement cost due to failure
2	0.3 to1 x replacement cost due to failure
3	1 to 3 x replacement cost due to failure
4	3 to10 x replacement cost due to failure
5	>10 x replacement cost due to failure

The asset criticality assessment compares calculated consequence cost with replacement cost. The banding is used for risk matrix in section 5.

4 OTHER ISSUES

4.1 Past Replacements

4.1.1 Conductor Past Replacements

Phase Conductor replacements are driven by poor condition and high criticality. Most of the conductor is in service from the original line construction. Other than works for diversion of small sections of lines to accommodate new infrastructure, the only significant condition related conductor replacements are presented in Table 5.

Table 5: Condition related conductor replacements

1972	500 kV HWTS-SMTS
1988	220 kV GTS-PTH
1998	220 kV RWTS- TTS
2008 to 2014	HYTS – APD

4.1.2 Ground Wire Past Replacements

GW replacements are driven by two main factors:

1. poor condition and high criticality and
2. telecommunication network upgrade i.e. upgrades of GW to OPGW.

Most of the ground wire is in service from the original line construction. Other than works for diversion of small sections of lines to accommodate new infrastructure and OPGW retrofits, the only condition related ground wire replacements are presented in Table 6.

Table 6: Condition related ground wire replacements

1997	220 kV YPS – ROTS 5/6
2000	YPS switchyard
2002	220 kV MKPS-MBTS
2002	220 kV BATS-BETS
2011	HYTS-APD
2015	HWTS-SMTS No 1
2015	KTS-WMTS
2015	HWTS-SMTS No 1
2016	KTS-GTS 2

4.2 Other Considerations

The other key issues associated with the transmission line conductor and ground wire fleet include:

1. The current condition assessment techniques for ACSR may not accurately assess the true condition of the internal steel strands. More advanced technologies offer more objective alternative such as the application of the SAIP system in conjunction with conductor sampling can improve the accuracy of condition data collected.
2. Accurately assessing the condition of mid span sections of conductor and ground wire during tower climbing inspections is difficult. More advanced technologies such as the application of the SAIP system in conjunction with conductor sampling can improve the accuracy of condition data collected.
3. Conductor clearance to ground need to be managed in accordance with AMS-10-75-21.
4. Foreign objects due to bird nests need to be proactively addressed by installing pre-made nests in the tower body to prevent bird-built nests on the crossarms in proximity of live conductors.

5. Replacement of conductor or ground wire is optimum when the residual strength of the conductor is sufficient to allow the use of the existing conductor as a pull wire. The consequences of running a conductor very close to its actual end of life are an increased operational risk and an increased replacement cost.
6. Replacement of phase conductors on transmission lines with limited outage availability require construction of a temporary bypass line which is very expensive.

5 RISK AND OPTIONS ANALYSIS

5.1 Overview

A conductor failure is defined as a loss of either of the electrical or mechanical functions of the conductor systems and can be caused by several different failure mechanisms.

Unassisted failures generally occur when the design is not perfectly aligned with the environment actions/forces resulting in a conductor failure i.e. wind induced vibration/fatigue, corrosion.

Assisted failures generally occur when environment actions cannot be cost effectively mitigated through design i.e. tree falling, lightning strike, fauna impact, acts of vandalism.

The following risk assessment is centred on the analysis of the unassisted failure mechanisms which develop into a fault over time.

Section 6 provides asset management improvement strategies to enable an even more accurate forecast of the conductor failure.

5.2 Risk Assessment Methodology

A quantitative risk assessment is adopted for transmission lines conductors and ground wires.

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,
- Consequence of failure:
  - bushfire risk cost,
  - value of unserved energy,
  - safety risk cost.
- Cost of replacement:
  - cost of replacement in 2019 $.

The risk analysis is summarised in a risk matrix which presents the GW and conductor span population as condition versus asset criticality.

The risk matrix is a tool, which outlines the volume of GW and conductor which is economic to be replaced during next regulatory period.

The risk assessment includes calculating the NPV for replacing each span. The red area of the risk matrix is adjusted to include only spans in high risk and with positive NPV for replacement.

5.2.1 Conductor Risk Matrix

Table 7: Conductor Risk Matrix – Count of Phase Conductor spans

Asset Criticality	C1	C2	C3	C4	C5	Total
5		535	352	25	4	**916**
4	4	2091	40	2		**2137**
3	21	2274	42		6	**2343**
2	954	1475	29		4	**2462**
1	4589	4860	25			**9474**
Total	**5568**	**11235**	**488**	**27**	**14**	**17332**

Table 8: Conductor Risk Matrix – Sum of Conductor span length [km]

Asset Criticality	C1	C2	C3	C4	C5	Total
5		184	121	7	2	**314**
4	0	800	11	0		**812**
3	3	785	11		2	**801**
2	361	629	6		2	**998**
1	1,788	1,891	8			**3,687**
Total	**2,153**	**4,290**	**157**	**8**	**5**	**6,613**

Table 7 and Table 8 outline a total of 41 spans or respectively 13 km of conductor route length in high risk.

5.2.2 Ground wire Risk Matrix

Table 9: GW Risk Matrix – Count of GW spans

Criticality	C1	C2	C3	C4	C5	Total
5	**1155**	**3286**	**371**	**165**	**81**	**5058**
4	**1918**	**3588**	**260**	**86**	**14**	**5866**
3	**1171**	**4129**	**264**	**90**	**16**	**5670**
2	**1326**	**1185**	**51**	**29**		**2591**
1	**6**	**54**	**2**	**0**	**0**	**62**
Total	**5576**	**12242**	**948**	**370**	**111**	**19247**

Table 10: GW Risk Matrix – Sum of GW span length [km]

Criticality	C1	C2	C3	C4	C5	Total
5	**423**	**1207**	**124**	**48**	**24**	**1826**
4	**744**	**1308**	**89**	**31**	**4**	**2176**
3	**484**	**1733**	**102**	**36**	**6**	**2361**
2	**553**	**474**	**18**	**14**	**0**	**1059**
1	**2**	**21**	**1**	**0**	**0**	**24**
Total	**2207**	**4742**	**334**	**129**	**34**	**7445**

Table 9 and Table 10 outline a total of 452 spans and respectively 149 km of ground wire route in high risk and with positive NPV.

5.3 Proposed Program of Works

5.3.1 Conductors Program of Works

The proposed program of works includes Phase Conductor spans in the top right corner of the risk matrix, i.e. spans with condition C4 and C5 and Asset Criticality 3, 4 and 5 and condition C5 with Asset Criticality 2. The program of works includes:

- 41 high risk spans, or 13 km, of conductor highlighted in Table 7 and Table 8
- 59 spans or 22 km conductor either side of these up to the next strain tower[7]
- Table 11 presents the total conductor program of works in route length [km] by voltage.

Voltage	500kV	330kV	275kV	220kV	66kV	Grand Total
Route Length [km]	7	2	1	15	9	**35**

Table 11: Conductor program of works route length [km]

5.3.2 Ground Wires Program of Works

The proposed program of works includes GW spans in the top right corner of the risk matrix and with positive NPV for replacement i.e. spans with condition C4 and C5 and Asset Criticality 4 and 5 and condition C5 with Asset Criticality 3.

The 2021-2025 program of works includes:

- 452 high risk GW spans or 149 km GW highlighted in Table 9 and Table 10;
- 527 GW spans or 177 km GW either side of these up to the next strain tower[7] and

Table 12 present the total ground wire program of works in route length [km] by voltage.

Voltage	500kV	330kV	220kV	66kV	Grand Total
Route Length [km]	13	10	295	7	**326**

Table 12: Ground wire program of works route length [km]

5.3.3 Conductor and Ground wire program of works

Table **13** presents top 15 circuits in order of route length of conductor and ground wire included in the program of works. Top 15 represents 86% of the program of works.

The replacement unit rates are higher for a span crossing over road or rail compared to a span without crossings. This is due to additional safety measures required when moving conductors and ground wire over roads and rail. Table 14 and Table 15 present the volume of spans with road and rail crossings in the scope of works.

[7] In practice a GW is replaced for the entire length between two strain/section termination towers

Circuit Name	66kV	220kV	275kV	330kV	500kV
MLTS-BATS 1		61.89			
YPS -ROTS 7		39.51			
YPS -ROTS 5		38.42			
HWPS-ROTS 1		31.39			
RWTS-TTS		26.38			
TTS -KTS 2		25.56			
TTS -BTS 1		11.86			
SMTS-TTS 2		10.69			
TTS -KTS 1		8.08			
ROTS-RTS 1		7.35			
ROTS-SVTS 1		7.26			
SMTS-TTS 1		6.55			
MSS -DDTS 1				6.12	
KTS-BLTS 1		5.19			
MWTS-LY NO.4	5.01				

Table 13: Top 15 circuits (Conductor and ground wire combined) in the program of works [km]

Table 14 illustrates the conductor crossings over road and rail infrastructure as a percentage of total conductor span population which is crossing road or rail. The data is presented by circuit voltage and VicRoads road class.

Line Xing Code	Description of VicRoads Road Class & Rail	Voltage [kV]					Total
		66	220	275	330	500	
5	Freeway & Rail		3				3
4	Highway & Rail		2	1			3
3	Arterial OR smaller than Arterial & Rail	2	4				6
2	Sub-Arterial						
1	Collector		8				8
0	No road or rail crossing	22	29	2	6	21	80

Table 14: Conductor span crossings

Table 15: Ground wire span crossingsTable 15 illustrates the ground wire crossings over road and rail infrastructure as a percentage of total ground wire span population which is crossing road or rail.

Line Xing Code	Description of VicRoads Road Class & Rail	Voltage [kV]					Total
		66	220	275	330	500	
5	Freeway & Rail		39				39
4	Highway & Rail		34			1	35
3	Arterial OR smaller than Arterial & Rail		52			1	53
2	Sub-Arterial		47		1	2	50
1	Collector		35			1	36
0	No road or rail crossing	6	779		6	19	810

Table 15: Ground wire span crossings

6 ASSET STRATEGIES

High level strategies to be adopted for prudent and efficient management of the transmission line conductor and ground wire fleet are:

6.1 New Assets

- All newly installed conductors are designed and constructed in accordance with current industry guidelines and standards.
- Replace ground wires with OPGW where required for communication purposes.
- Install AAAC in area subjected to extreme corrosivity to ensure maximum life. AAAC is more corrosion resistant than ACSR.

6.2 Inspection

- Continue improving the Smart Aerial Image Processing (SAIP) technology to assess the condition of conductor and ground wire systems. A program of inspection involving a full coverage over a 3-year period followed by a reduced ongoing program to cover 50% in each following 3-year period is recommended.
- Introduce a routine inspection program in terminal stations
- Continue improving the existing transmission line inspection regime as outlined in LPP 09-01 and LPP 09-06.

6.3 Maintenance

- Replace or repair defective conductor and ground wire assets as part of corrective maintenance tasks.
- Manage the transmission line ground clearance in line with AMS 10-75-21.

6.4 Replacement

- Replace 100 span of phase conductors by 2027
- Replace 979 ground wire spans by 2027
- Coordinate the ground wire replacements based on condition with those based on telecommunication upgrades.

APPENDIX A ACRONYMS

AAAC	All Aluminium Alloy Conductor
AAC	All Aluminium Conductor
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
AIS	Availability Incentive Scheme
AL	
ACSR	Aluminium Conductor Steel Reinforced
ALS	Aerial Laser Survey
CA	Condition Score
Cr	Criticality (Consequence) Score
EHV	Extra High Voltage
FMECA	Failure Mode, Effect and Criticality Analysis
FMI	Field Mobile Inspection
GW	Ground Wire
HV	High Voltage
OPGW	Optical Fibre Ground Wire
RCM	Reliability Centred Maintenance
SAIP	Smart Aerial Image Processing

APPENDIX B CORROSIVITY ZONES ON THE VICTORIAN TRANSMISSION NETWORK

[C-I-C]

APPENDIX C BUSHFIRE CONSEQUENCES ON THE VICTORIAN TRANSMISSION NETWORK

[C-I-C]