AMS – Victorian Electricity Transmission Network

Transmission Line Conductors and Ground Wires (PUBLIC VERSION)

Document number	AMS 10-79
Issue number	2
Status	Approved
Approver	J. Dyer
Date of approval	25/08/2015

ISSUE/AMENDMENT STATUS

Issue Number	Date	Description	Author	Approved by
0	06/10/08	Prelim Draft	G. Karutz	
0.1	04/03/09	Initial Draft Version 1	G. Karutz	S. De Silva
0.2	16/11/12	Restructure and reformat. Updated risk and strategy sections.	C. Rabbitte	D. Postlethwaite
1	15/12/12	Final draft	C. Rabbitte	D. Postlethwaite
2	25/08/15	Review and update	M. Tan	J. Dyer

Disclaimer

This document belongs to AusNet Services and may or may not contain all available information on the subject matter this document purports to address. The information contained in this document is subject to review and AusNet Services may amend this document at any time. Amendments will be indicated in the Amendment Table, but AusNet Services does not undertake to keep this document up to date.

To the maximum extent permitted by law, AusNet Services makes no representation or warranty (express or implied) as to the accuracy, reliability, or completeness of the information contained in this document, or its suitability for any intended purpose. AusNet Services (which, for the purposes of this disclaimer, includes all of its related bodies corporate, its officers, employees, contractors, agents and consultants, and those of its related bodies corporate) shall have no liability for any loss or damage (be it direct or indirect, including liability by reason of negligence or negligent misstatement) for any statements, opinions, information or matter (expressed or implied) arising out of, contained in, or derived from, or for any omissions from, the information in this document.

Contact

This document is the responsibility of the Asset Management division of AusNet Services. Please contact the undersigned or author with any inquiries.

John Dyer
AusNet Services
Level 31, 2 Southbank Boulevard
Melbourne Victoria 3006
Ph: (03) 9695 6000

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 24 per cent of the population has been in service for more than 50 years, this figure will increase to 58 per cent by 2022. A significant proportion of the ground wire population is now reaching its original design life and much of the conductor population will reach its design life in the next 10-20 years. 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.

Heavy corrosion of ACSR was the root cause of a major functional failure which took place on the HYTS-APD 500 kV line in 2008 after just 25 years of service. The HYTS-APD 500 kV lines are situated close to Victoria's western coast and are exposed to coastal salt deposition. Since the functional failure in 2008 AusNet Services has replaced sixteen kilometres (route length) of conductor between HYTS and APD. The conductor closest to the coast displayed the worst deterioration and has been replaced as a priority.

AusNet Services has applied optimised RCM risk modelling techniques to the entire conductor and ground wire fleet in order to establish a prioritised replacement program. This approach has employed probabilistic risk modelling techniques to establish a targeted and economic replacement program. The dependability model shows that material risks are generated from the Condition 4 and 5 steel ground wires. There is an approved project (XC77) to replace approximately 79 km of ground wires by 2017. An additional 226 km ground wires are forecast for replacement before 2022. No conductor is forecast for replacement before 2022.

Visual inspection of ACSR presents challenges in assessing the condition of the inner steel strands. Visual inspection techniques are limited in their ability to support the development of optimised conductor and ground wire replacement programs. Smart Aerial Image Processing (SAIP) inspection of conductor is in the process of being adopted as the standard inspection technique, this advanced condition monitoring technique is additional to the existing business as usual patrols and tower climbing practices.

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.
- AAAC is more corrosion resistant than ACSR and is suitable to be used in area subjected to extreme corrosivity to ensure maximum life.

1.2 Inspection:

- Adapt the use of Smart Aerial Image Processing (SAIP) technology to assess the condition of conductor and ground wire. 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.
- Complete Aerial Laser Surveys (ALS) using LIDAR laser technology on the remaining three per cent of transmission lines by 2022.
- Implement the use of the Field Mobile Inspection (FMI) system as the primary means of capturing condition assessment data. The FMI system must be designed to update the transmission asset management system as part of automated process.

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

1.3 Maintenance:

- Replace or repair defective conductor and ground wire assets as part of corrective maintenance tasks.
- Develop and implement a risk management plan for all transmission line spans identified as not meeting current design standard by 2022.

1.4 Replacement:

- There is an approved project (XC77) to replace approximately 79 km of ground wires on the KTS-WMTS and KTS-GTS No.2 220 kV lines by 2017.
- Replace additional 226 km of ground wire (three per cent of the ground wire fleet) which have been deemed economically justified for replacement by April 2022. Ground wire replacements will address the highest risk spans as a priority.

2 Introduction

2.1 Purpose

The purpose of this document is to define the asset management strategies for AusNet Services' population of transmission line conductors and ground wires.

2.2 Scope

This asset management strategy applies to all conductors, ground wire (including optical fibre ground wire) and fittings associated with the Victorian electricity transmission network operating at voltages of 66 kV and above. 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.

3 Asset Summary

3.1 Population

The total route length of Extra High Voltage (EHV) and High Voltage (HV) phase conductor on the transmission network exceeds 6,500 kilometres as at November 2014. Phase conductors operate at five standard voltages including 500 kV, 330 kV, 275 kV, 220 kV and 66 kV. EHV conductors and some HV conductors are shielded from lightning strike by approximately 7,470 kilometres of ground wire and optical fibre ground wire (OPGW) positioned above phase conductors on the structure and within terminal stations. Phase conductor lengths are reported as route length which counts all three phases on an individual span as one asset. Ground wire lengths are reported as actual length which means that each span of ground wire is counted as an individual asset even on towers containing two ground wires.

Vibration dampers are fitted to most conductors and some ground wire to minimise the effects of wind induced Aeolian vibration. Fittings and hardware provide mechanical links between conductors and other transmission line assets while conductor spacers provide stability to bundled phase conductors.

Conductors and ground wires are supported by transmission line structures[2] which ensure that adequate clearances are maintained between electrically energised apparatus and objects on line easements[3]. Structures and associated steel work are insulated from the live conductors using transmission line insulators[4]. Conductors are an essential component of a transmission line system. All newly installed conductors are designed and constructed in accordance with current industry guidelines and standards[5].

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[6,7].

The number of phase conductor strands and their 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 conductors on the transmission network by code name include panther, canary and finch (early imperial sizes) and lemon, mango, orange, paw paw, and olive (later metric equivalents).

Table 1 displays cross sectional photographs of ACSR with aluminium strands surrounding steel strands and AAAC which contain aluminium alloy strands only.

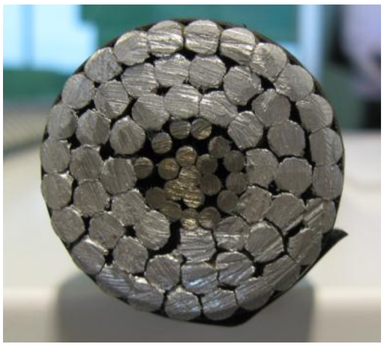
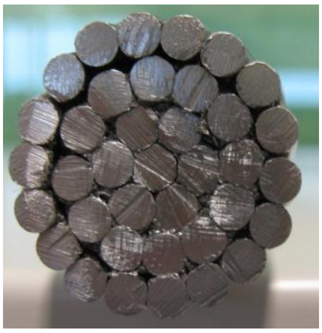
	
ACSR	AAAC

Table 1 – Photographs of ACSR and AAAC

[2] AMS 10-77 Transmission Line Structures.

[3] AMS 10-65 Transmission Line Easements.

[4] AMS 10-75 Transmission Line Insulators.

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

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

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

There are three different types of ground wire in use on the transmission network including steel, ACSR and OPGW. Traditional ground wires perform two key functions including 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.

Table 2 provides a summary of conductor and ground wire lengths for different types and operating voltages.

Voltage	ACSR	AAC	AAAC	Steel GWIRE	ACSR GWIRE	OPGW	Total (km)
500 kV	1450		30	2	1967	464	3913
330 kV	735		4	1276		161	2176
275 kV	157				156		313
220 kV	4011			2045	100	1194	7350
66 kV	149	27		104			280
Grand Total (km)	6501	27	34	3427	2224	1819	14032

Table 2 – Conductor and ground wire lengths (km) for different voltages

ACSR is the most common phase conductor on the transmission network contributing 99 per cent of the total route length. This conductor combines the excellent electrical properties of aluminium with the mechanical properties of steel. AAAC is more corrosion resistant than ACSR. A portion of the Heywood to ALCOA Portland 500 kV line reconstructed in 2011 used an AAAC conductor in anticipation of the highly corrosive environment. This conductor (previously ACSR) failed in 2008 after in service for 25 year and the decision has been taken to use a fully greased AAAC as the replacement conductor to ensure maximum life in this area subjected to extreme corrosivity (see Appendix A).

Figure 1 displays conductor length by voltage and type. The 220 kV network contains 61 per cent of the total route length and is served by ACSR conductor. The combined route length of AAAC contributes less than 1 per cent of the total network length.

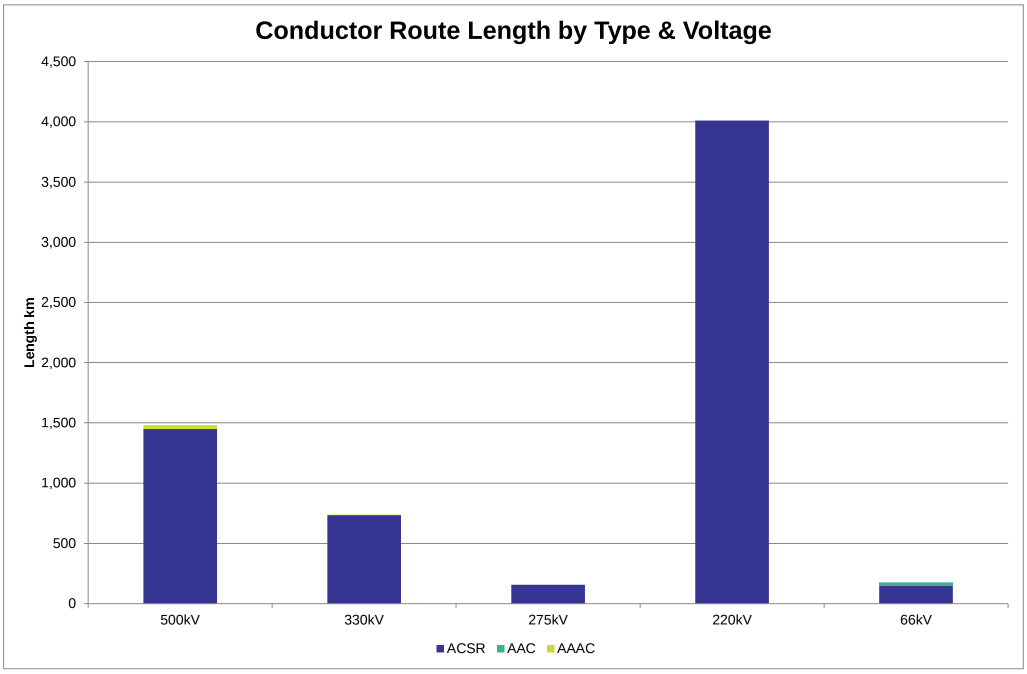


Figure 1 – Conductor route length by voltage and type

AusNet Services has implemented extensive ground wire replacement programs over the last two decades. The replacement programs have been primarily driven by the need to upgrade the networks communications systems to meet the performance specifications of the National Electricity Market. Communication upgrades resulted in the replacement of 24 per cent of ground wire with OPGW. Steel ground wire and ACSR ground wire make up the remaining 46 per cent and 30 per cent of the total ground wire length respectively. Steel and ACSR ground wire in service generally date back to when the line was originally built and have the same install date as the structures which support them.

Figure 2 displays ground wire length by voltage and type. The 220 kV network contains the highest number of double circuit towers[8] when compared to other voltage classes which generally contain one ground wire per circuit. 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.

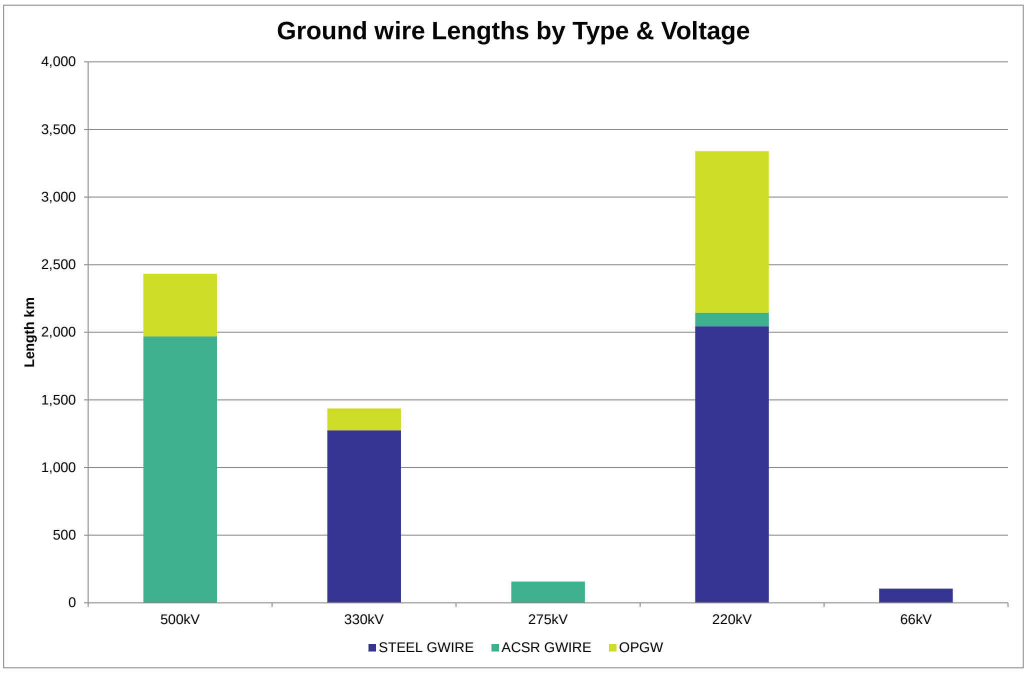


Figure 2 – Ground wire Length by circuit voltage and type

3.2 Age Profile

The average service age[9] of the transmission line conductor and ground wire populations is 45 years and 35 years respectively. The average ages of conductor and ground wire for each voltage class is shown in Table 3 below. The average age of conductor and ground wire is highest on the 220 kV and 330 kV network respectively.[10]

[8] AMS 10-77 Transmission Line Structures.

[9] Service age for conductor & ground wire is based on the installation date.

[10] The expected asset lives of conductors and ground wires at low, moderate, severe and very severe corrosivity environment are 80, 70, 40 and 30 years respectively.

Average Service Age (years)		
Voltage Class	**Conductor**	**Ground wire**
500 kV	35	32
330 kV	47	43
275 kV	26	26
220 kV	49	35
66 kV	39	40
All	**45**	**35**

Table 3 – Average age of conductor and ground wire (as at November 2014)

The Victorian transmission network firstly consisted of 220 kV lines built to connect Melbourne and large cities in the North West and North East of the state to generators in the La Trobe 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 1950's and early 1980's. 500 kV lines from the La Trobe Valley to Melbourne provided further capacity to meet demand growth and to support heavy industry in South West Victoria.

Figure 3 shows the service age of the transmission line conductor and ground wire population by operating voltage. Approximately 24 per cent of the conductor and ground wire fleet have been in service for more than 50 years, this figure is forecast to be to approximately 58 per cent by 2022.

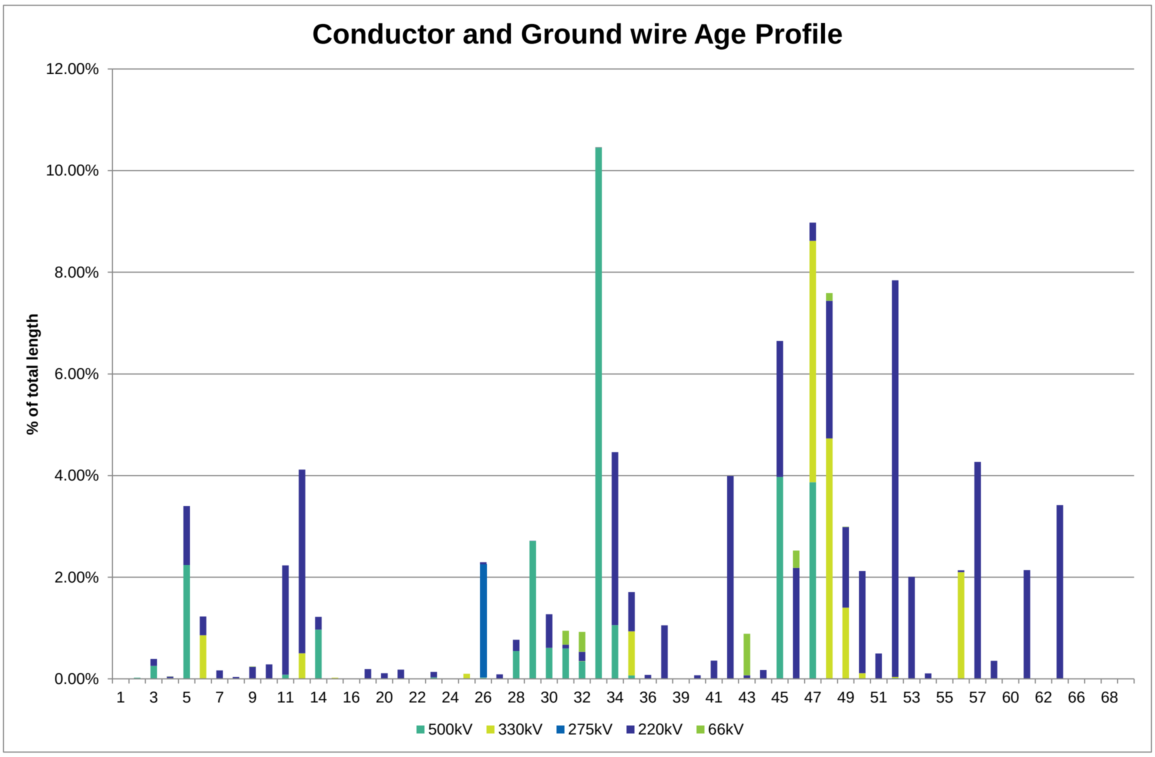


Figure 3 – Conductor & ground wire service age profile by Voltage

The first transmission lines were built using ACSR galvanised (GZ) conductor and steel ground wire; these were the only conductor and ground wire types used during line construction until 1965. After 1965 ACSR (GZ) ground wire was adopted for construction of the 500 kV network, ACSR ground wire became the preferred ground wire type for all line voltages during the 1980's. The use of OPGW as a substitute for steel and ACSR ground wire began in the late 1980's.

Figure 4 displays the age profile of transmission conductor and ground wire by type. OPGW has been used extensively to upgrade the communications[11] network during the last 15 years. Apart from a conductor replacement project at HYTS-APD 500 kV line (due to coastal/salt corrosion) and RWTS-TTS 220kV (due to industrial corrosion) there have been minimal phase conductor replacements on the transmission network.

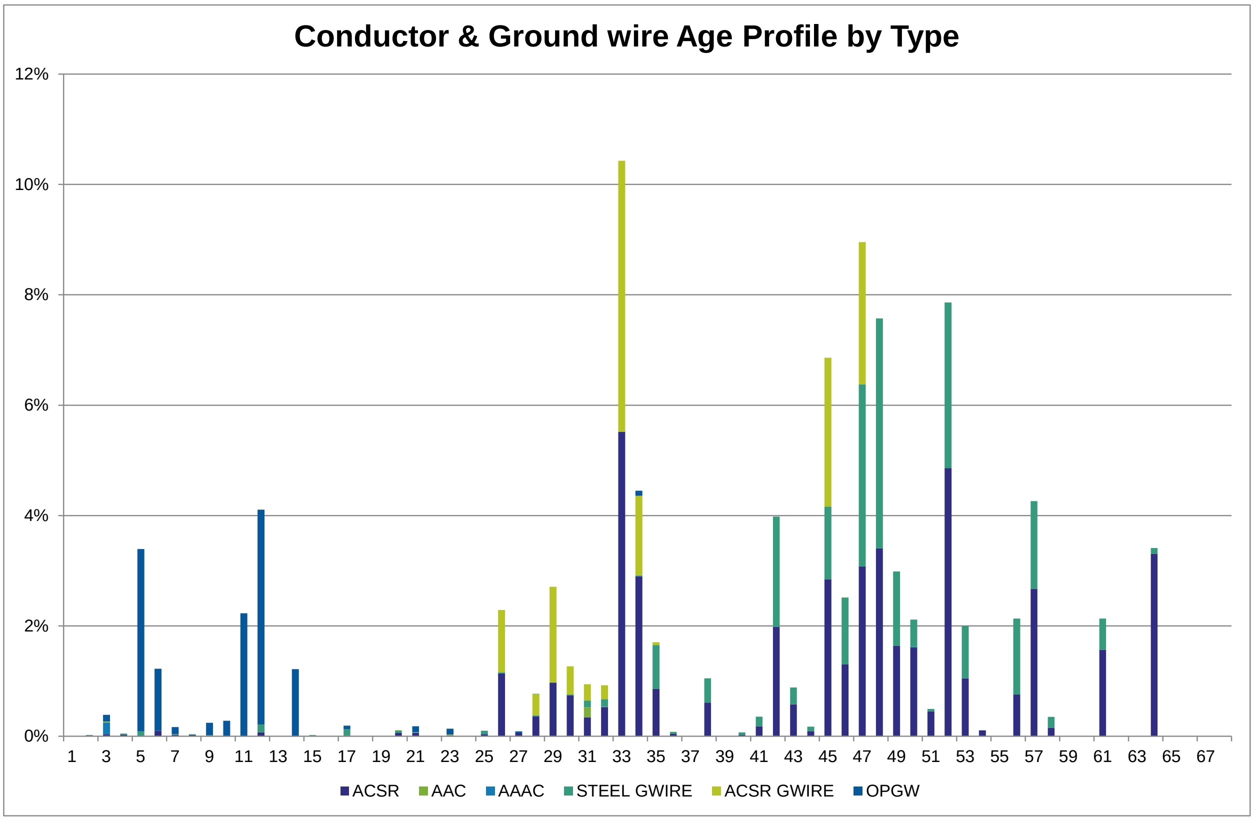


Figure 4 – Conductor & ground wire service age profile by Type

3.3 Condition

This section provides an overview of the condition of transmission line conductor and ground wire. AusNet Services assesses the condition of conductor and ground wire using different techniques. Some of these techniques, such as tower climbing inspections, are well established while others, such as Smart Aerial Image Processing (SAIP), has just been adopted as the standard inspection technique and have not yet been applied network wide.

3.3.1 Tower climbing inspections

Condition of transmission line conductor and ground wire is primarily assessed during tower climbing inspections which are now conducted for each transmission structure at a maximum interval of once every 37 months. Condition data collected during this well established process is used to develop asset management strategies. Conductors and ground wire are assigned a condition grade from a scale between C1 (best) and C5 (worst) against specific grading parameters. Condition grades focus on factors which are known to adversely affect the electrical or mechanical properties of the assets including corrosion and broken strands.

Condition grading of ACSR can be difficult to perform visually as the corrosion starts and progresses at the interface between the steel core of the conductor and the inner aluminium strands before it is visible at the outer aluminium strands. This key factor requires the skilled line inspector to identify the presence of white powder or signs of bulging which are indications that the steel core has begun to degrade. In some cases the time between detecting the onset of steel core corrosion and failure of the asset, technically known as the P-F

[11] AMS 10-56 Communications Systems.

Interval, can be as short as three to five years. Remaining life of the conductor is very difficult to assess accurately using this basic inspection method; current inspection practices may be unsuitable for identifying large populations of deteriorating conductor. There are technologies available, such as SAIP, which offer more accurate alternatives for assessing steel core condition. AusNet Services has recently adopted SAIP as the standard inspection technique for assessing the condition of transmission conductor and ground wire to ensure future maintenance and investment is optimised.

Table 4 below outlines the transmission line conductor and ground wire condition grades and descriptions against each different grading parameter.

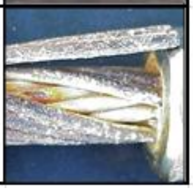
Condition grade	Conductor (& ACSR ground-wire)		Steel Ground-wire	
C1	New or oxidised.		No rust	
C2	First signs of white powder		First rust	
C3	Just visible corrosion bulge		Patchy rust	
C4	Bird caging, corrosion, bulge.		No Zinc	
C5	Broken Strand(s)		Pitted rust	
Failed	Exploded		Broken Strand	

Table 4 – Transmission line insulator condition grades and descriptions

Conductor and ground wire condition grades are considered along with other factors such as age, type, consequence of failure and electrical line loading design when taking decisions with respect to management of the asset.

Figure 5 and Figure 6 show the condition of transmission line conductor and ground wire. The majority (96 per cent) of conductor and ground wire spans are in good to average condition displaying minimal levels of rust or corrosion in line with grades C1, C2 and C3. The remaining four per cent of the conductor and ground wire spans in C4 and C5 are displaying concerning levels of corrosion which will require remedial attention within ten years.

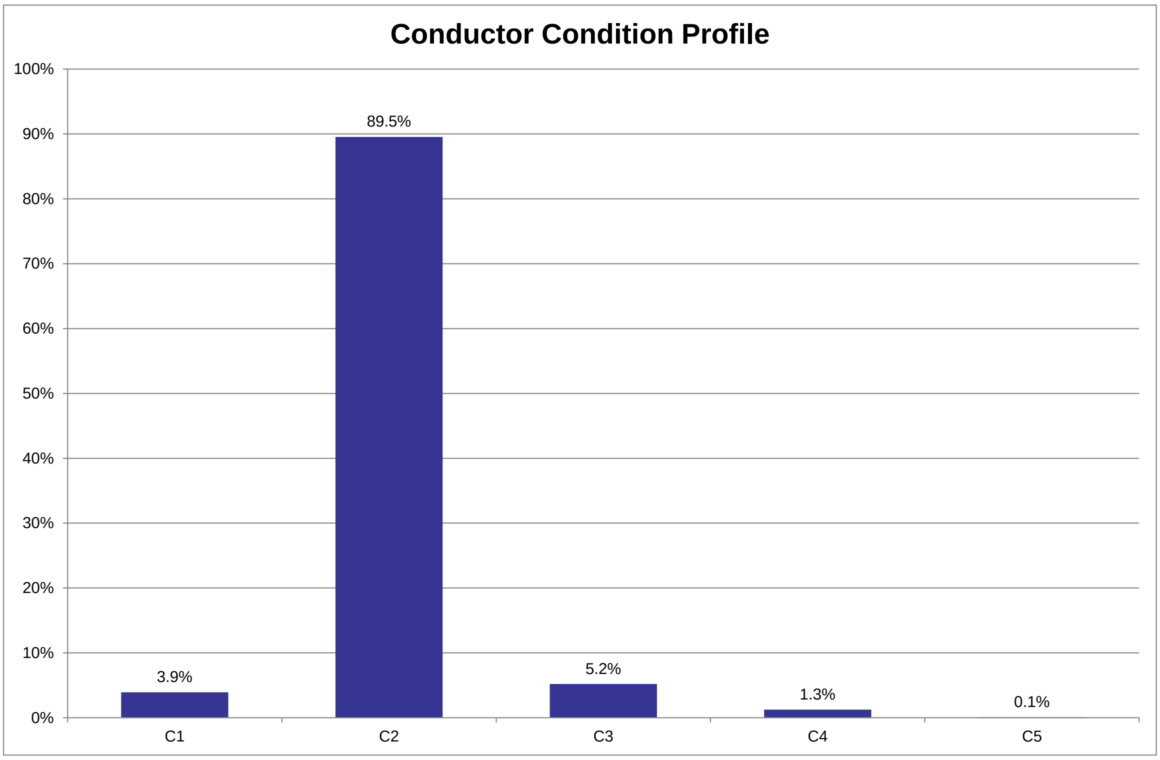


Figure 5 – Conductor condition by grade

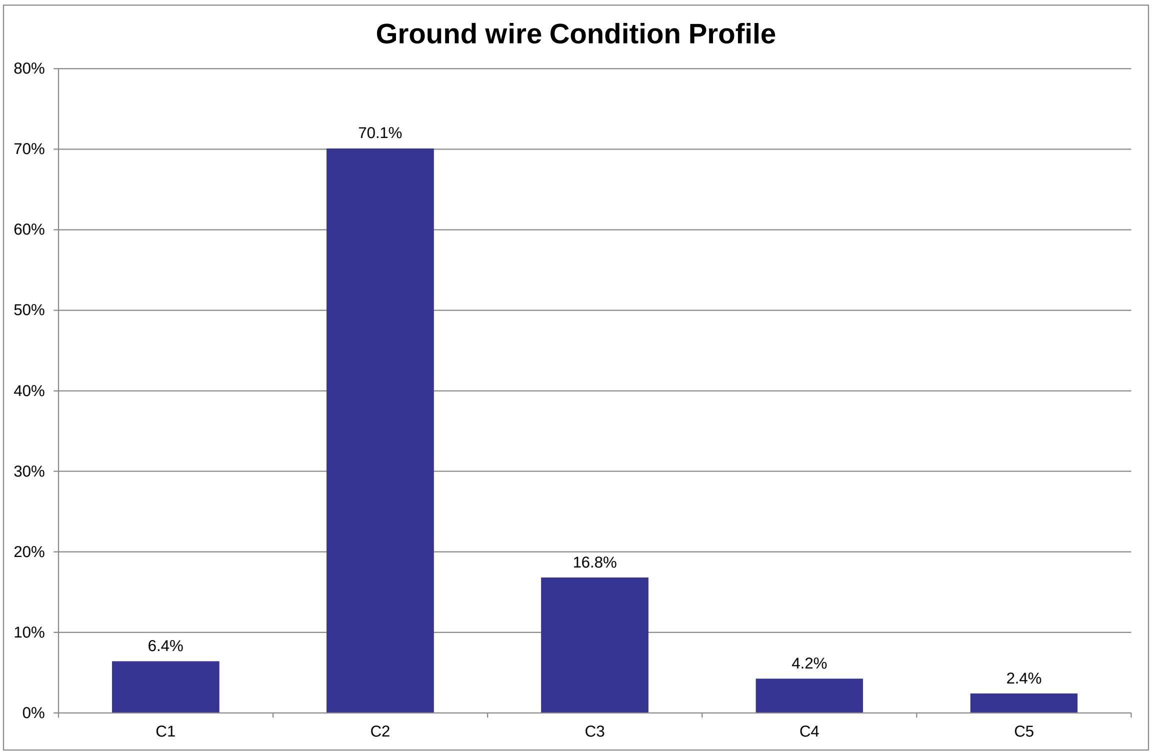


Figure 6 – Ground wire condition by grade

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. In order to manage the effects of corrosion in a prudent manner corrosivity classifications are assigned to transmission line assets. There are a total of four corrosivity zones including very severe, severe, moderate and low.

Figure 7 shows the proportion of transmission line conductors and ground wires located in each of the four corrosivity zones. A map displaying a spatial view of transmission line assets within the four corrosivity zones is included in Appendix A. Fifty three per cent of the transmission line conductor and ground wire population are situated in the low corrosivity zone. The HYTS-APD 500 kV lines No.1 and No.2 are situated in the very severe corrosivity zone. They supply power to an industrial plant situated at Portland on Victoria's western coast. Heavy corrosion of ACSR was the root cause of a major functional failure which took place in 2008 after 25 years of service. As a result of this failure, a project to replace sixteen kilometres (route length) of conductor between HYTS and APD conductor with AAAC was undertaken.

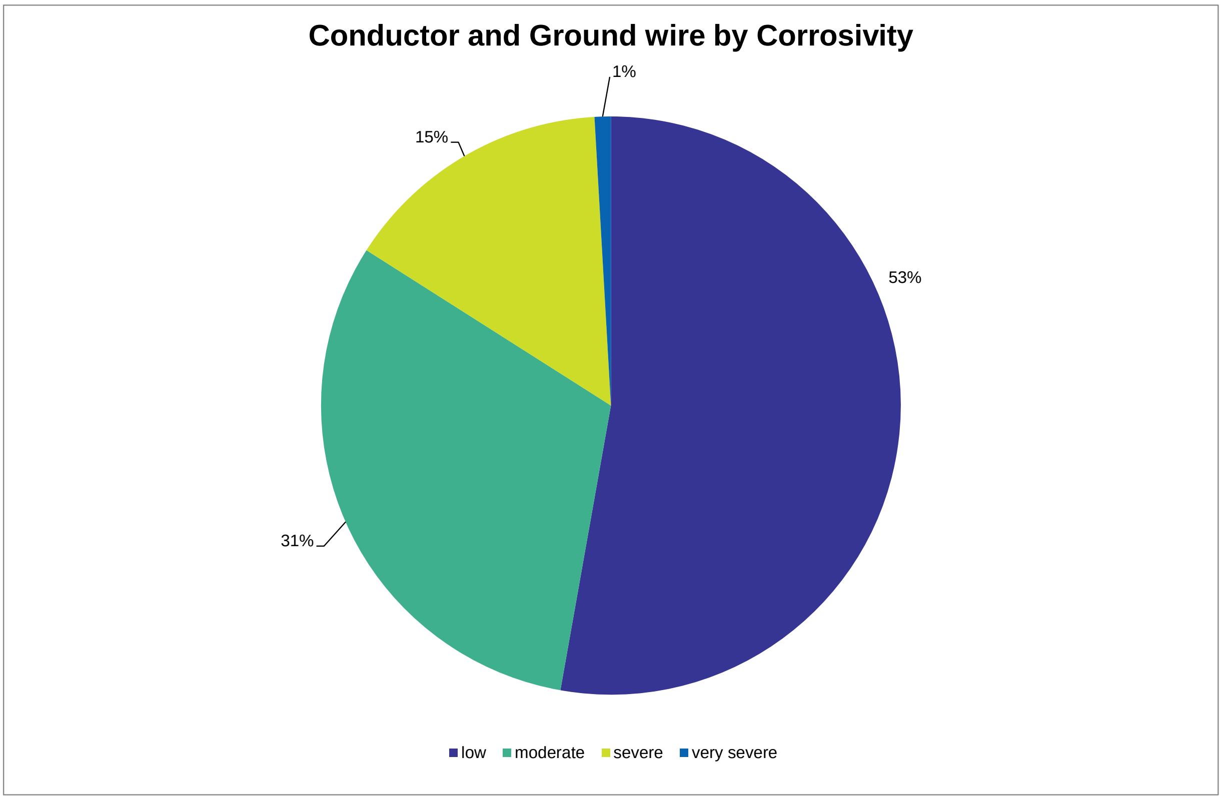


Figure 7 – Conductor and ground wire location by corrosivity zone

As discussed, coastal salt deposition and industrial pollution are the main factors contributing to the degradation of conductor and ground wire condition. This is demonstrated by the percentage split of conductor and ground wire spans in each of the four corrosivity zones for different condition grades as illustrated in Figure 8. Only one per cent of the spans with condition grade C5 are situated in the very severe corrosivity zone, the very low percentage is attributed to the replacement project at HYTS-APD 500 kV line (project X890).

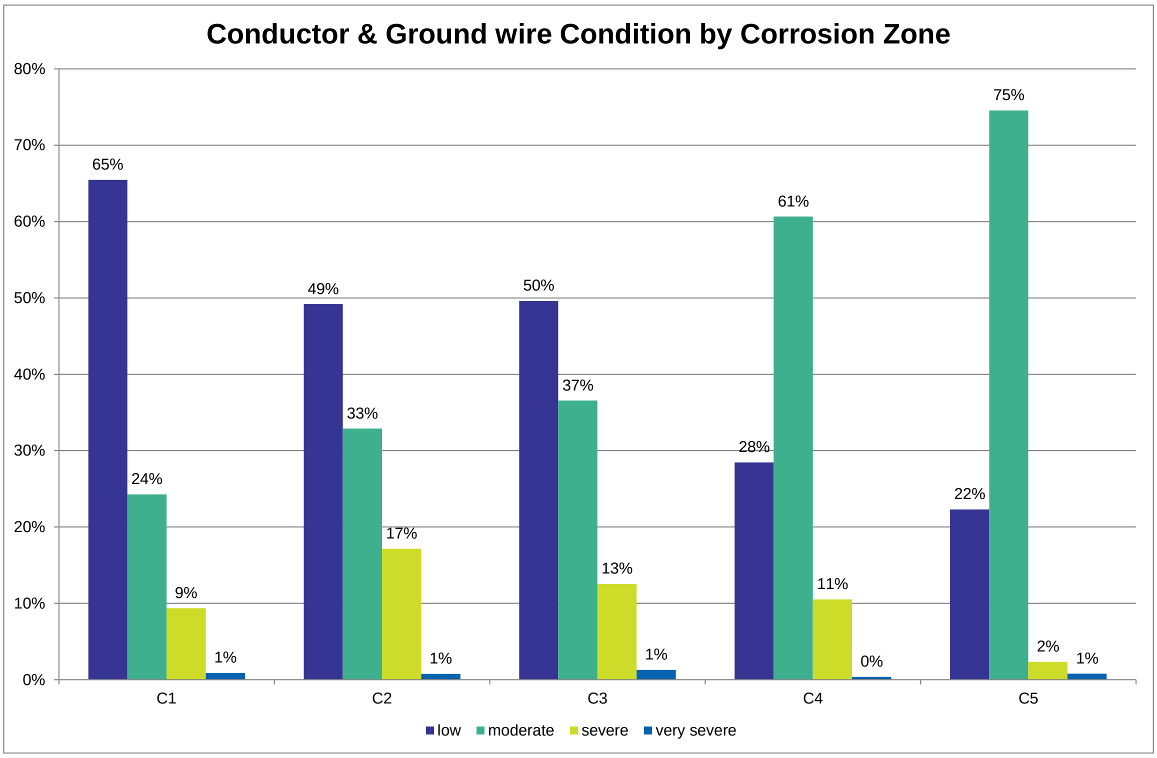


Figure 8 – Conductor and ground wire condition by corrosivity zone

3.3.2 Smart Aerial Image Processing (SAIP)

Accurate detection of early signs of corrosion of ACSR is difficult to achieve through visual inspection. Although it is possible to assess levels of corrosion of outer aluminium strands, a clear indication of the steel core's condition is difficult to obtain. In order to visually inspect the steel core condition, removal, testing and analysis of representative samples is required. This approach is costly, involves lengthy outages and requires considerable investment of resource. Corrosion is not necessarily uniform along the length of the conductor, so sampling may not accurately predict its true condition.

Failure of ACSR on the HYTS- APD 500 kV line in 2008 demonstrated that AusNet Services' existing conductor monitoring practices had limitations and may not have accurately assessed the condition of the core steel strands. Identifying conductor corrosion at mid span sections is especially difficult by way of visual inspection. In response to this, AusNet Services completed a trial on an emerging technology known as SAIP.

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 conductor corrosion or damage. This technology enables the efficient capture of conductor images spanning long distances of specified transmission lines. Images captured are analysed using specially developed software which automates the identification of signs of corrosion including the presence of white powder, conductor bulging or broken strands.

AusNet Services has used this technology to great effect in assessing the condition of conductor and, in particular, the ACSR ground wire on the HWTS-SMTS 500 kV line. The SAIP system revealed numerous sections of ground wire which are heavily corroded and resulted in an approved project (XC31) to replace the one hundred spans of ground wire.

With ACSR being the most common material on the network and the limitations of the current inspection techniques to assess the entire length of the spans, it is considered that increased inspection requirements will be needed to develop more accurate knowledge of condition to inform future investment and maintain high reliability and safety. AusNet Services recognises the great technical and financial benefits associated with this technology and is in the process of adopting SAIP as the standard inspection technique.

3.4 Performance

Analysis of conductor and ground wire performance is detailed in this section. AusNet Services employs the use of 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.

3.4.1 Suspended failures

Defects that are detected and repaired before they cause a functional failure (i.e. outage) are defined as suspended failure.

In accordance with the accepted Electricity Safety Management Scheme AusNet Services has adopted strict line patrolling and line inspection policies which are aimed at objectively assessing the condition of transmission line components and identifying those assets which are not fit to remain in service. Those deemed not fit for service are replaced via work orders raised in Enterprise Asset Management information system.

Since 2007 there have been a total of 1,622 suspended failures, predominantly caused by the conductor and ground wire hardware and fittings. Less than five per cent of the suspended failures were due to deteriorated conductors and ground wires such as broken strands and corrosion as shown in Table 4. The majority of suspended failures were caused by wear and hot joints or high resistance palm connections representing 31% and 20% of suspended failures since 2007. Figure 9 displays the volume of work orders completed since 2007.

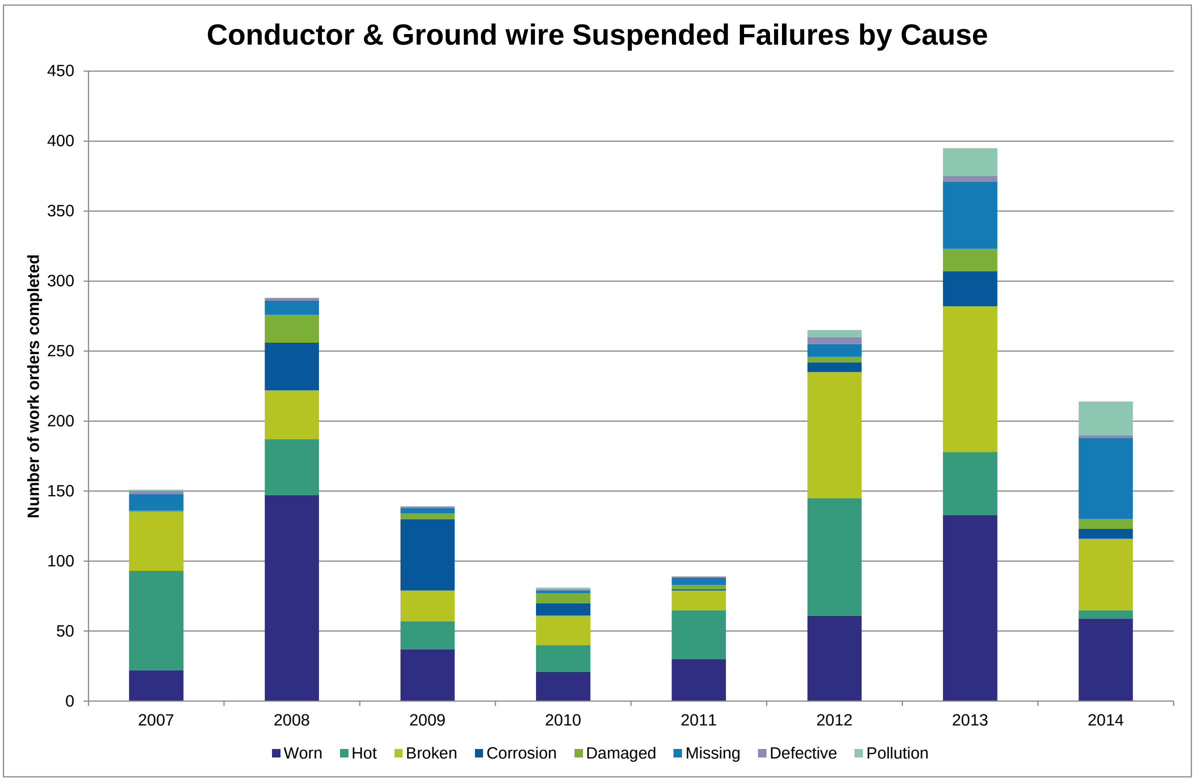


Figure 9 – Conductor and ground wire suspended failures by cause

Conductor and ground wire support systems at structures are essentially linked mechanical components which are subject to wear through movement. Connections can be ball and socket, clevis–tongue or via bolt, pin or shackle with movement caused by small amplitude conductor vibration or insulator swing at suspension points. The typical components replaced since 2007 due to the effects of wear included conductors and ground wire fittings, conductor spacers and dampers which had become loose.

Corrosion of conductor joints and termination palms increases the electrical resistivity of the connection components resulting in elevated operating temperatures. Thermo vision inspections assist with the identification of hot joints and hot palm connections for replacement or refurbishment as part of corrective maintenance tasks[12]. The highest number of works order raised to rectify hot joints and palms was in 2012. The thermo vision inspection program began in 1998 and takes place on every circuit on a three year continuous cycle.

A considerable increase in completed work orders occurred in 2008 mainly as a result of defects identified during the tower climbing condition assessment program which was launched in 2006.

3.4.2 Functional failures

There have been seven incidents[13] of conductor functional failure over a period of 42 years. A conductor functional failure is an incident which prevents the safe flow of electricity from one terminal station to another. 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 conductor or ground wire falling to the ground or onto phase conductors below.

The first conductor functional failure took place on the HWTS-SMTS 500 kV line in 1972 due to corrosion of ACSR caused by industrial pollution from a paper manufacturing plant. This initial failure was followed by a 25 year failure free period. The remaining six conductors and ground wire functional failures occurred within a 16 year period from 1998 to 2014. The incidents are described in sections 3.4.3 and 3.4.4 below.

Figure 10 displays the history of conductor functional failures on the Victorian electricity transmission network.

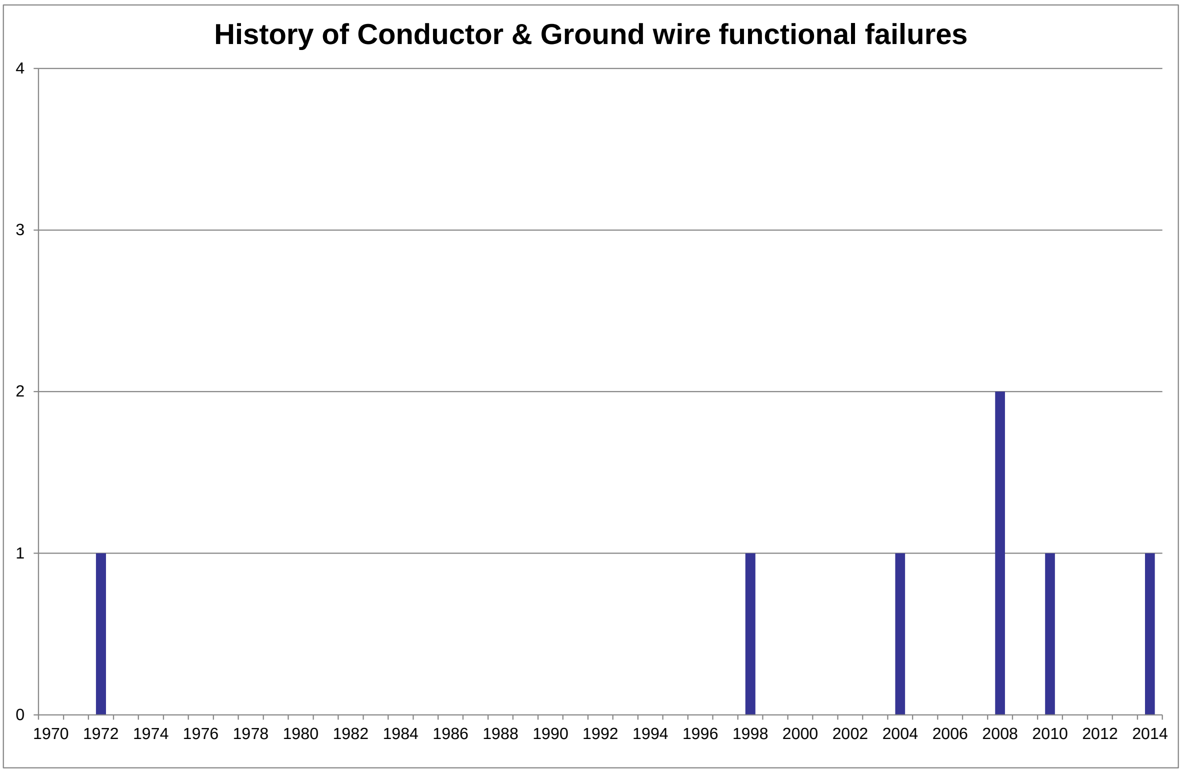


Figure 10 – History of conductor and ground wire functional failures

[12] AMS 10-19 Plant & Equipment Maintenance.

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

3.4.3 Corrosion

A total of three or 43 per cent of all conductor and ground wire functional failures have been caused by corrosion. All three incidents have taken place in areas of extreme industrial or coastal pollution where degradation of conductor condition has been accelerated. The first incident took place in 1972 and was caused by pollution from a paper manufacturing plant in Maryvale. The second failure occurred in 1997 on the RWTS-TTS 220 kV circuit on a section of line which is adjacent to a metal smelting plant in Dalton Road, Thomastown. Pollution from the plant caused accelerated corrosion of the steel core in the ACSR reducing its tensile strength below breaking limits. The most recent corrosion related failure took place in 2008 and was caused by salt deposition on the HYTS-APD 500 kV line. Once again extreme corrosion of steel strands within the ACSR promoted accelerated reductions in ultimate tensile strength (UTS) and failure after just 25 years of service.

3.4.4 Vandalism, fatigue and lightning strike

Vandalism, fatigue and lightning strike have been the root cause of the remaining four conductor and ground wire functional failures. A terminating shackle situated on a rack in HWTS failed in 2004 due overheating caused by circulating current. A phase conductor failed after rifle fire damage on the MBTS-EPS line in 2008. In 2010 OPGW on the BATS -BETS 220 kV line failed after sustaining a lighting strike during a storm event. In 2014, the ROTS- YPS No.8 220 kV line tripped due to a failed middle phase insulator suspension clamp of T342 bridging conductor.

Figure 11 displays the distribution of conductor and ground wire functional failures on the Victorian transmission network.

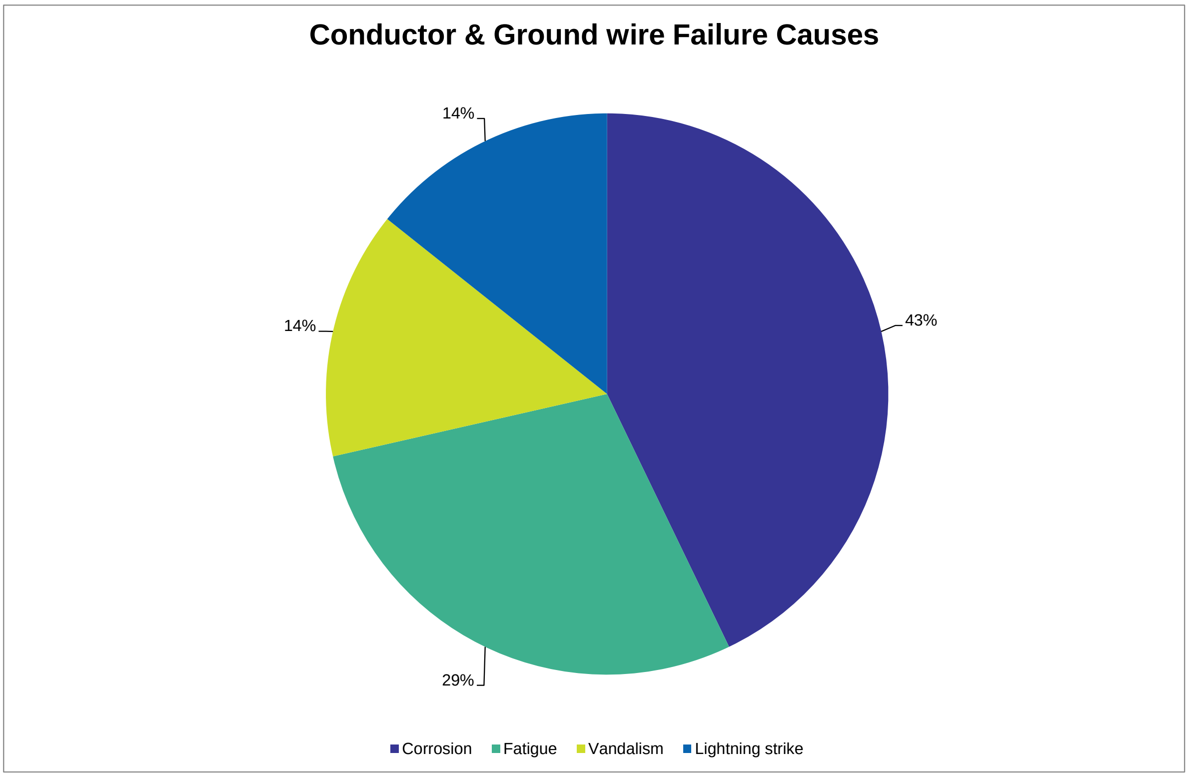


Figure 11 – Conductor and ground wire cause of failures

Reliability of the conductor and ground wire fleet has remained stable over the last three to five years as the high concentration of failures experienced in the early 2000's has alleviated. The current Mean Time Before Failure (MBTF) of the fleet is approximately 9.29 years; the trend is relatively stable since 2010. Figure 12 displays the change in conductor and ground wire MTBF since 2002.

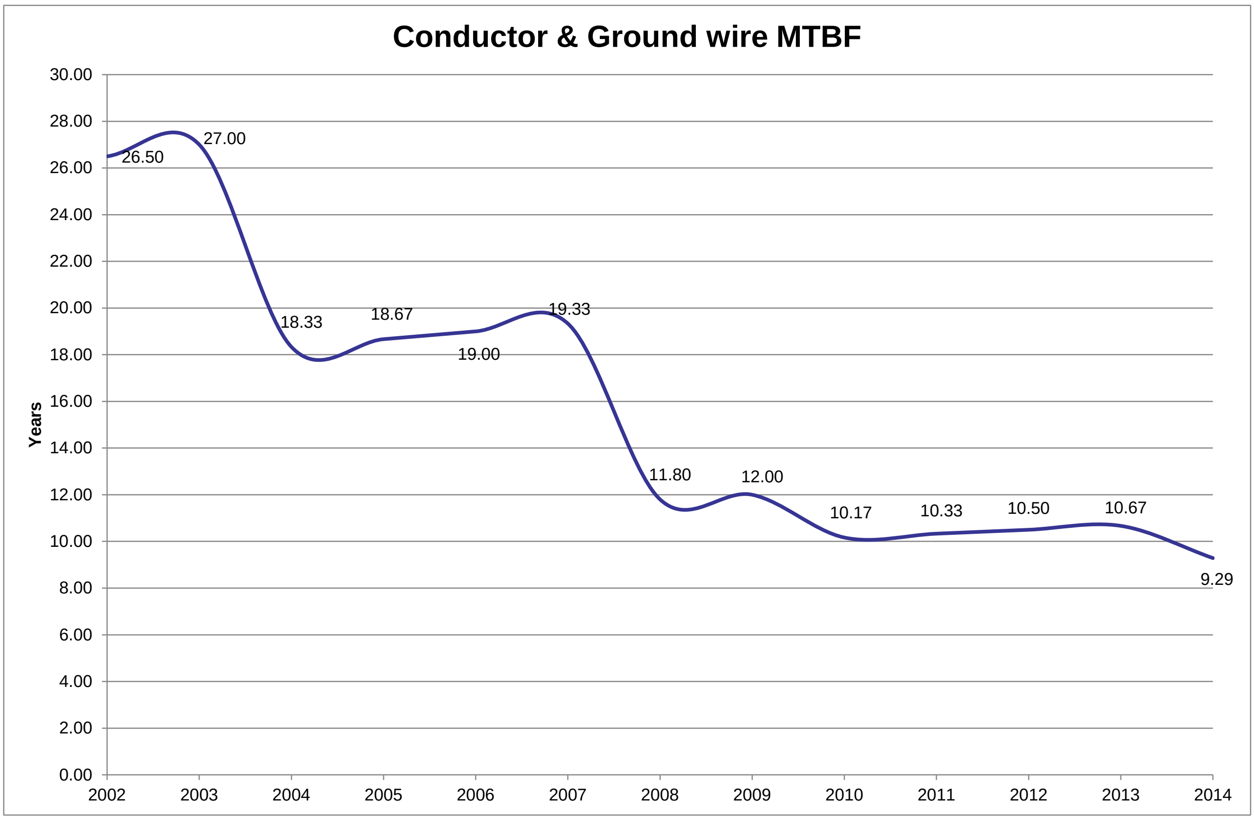


Figure 12 – Conductor and ground wire MTBF

Although corrosion is not the most dominant cause of functional failure to date; concern is mounting regarding the continuing degradation of considerable proportions of the fleet, especially those situated in corrosive environments. With ACSR being the most common material on the network (more than 60 per cent of the conductor and ground wire fleet), these concerns are heightened by issues associated with accurately assessing condition of ACSR as discussed in section 3.3.2. AusNet Services predicts that failure to implement improved condition assessment techniques and targeted replacement programs for high risk spans will result in increasing risk of conductor and ground wire failures.

3.4.5 Failure Effects

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. Major conductor and ground wire failures can lead to three different consequence types including health and safety, bushfire ignition and network performance. These consequences can be quantified using the 1 – 5 scoring system shown on the vertical axis of AusNet Services' risk matrix which is displayed in Figure 13.

Analysis of the MTBF for conductor and ground wire guides the likelihood scoring in an objective fashion. A MTBF of 9.29 years indicates that there have been functional failures once every 9.29 years on average which corresponds to an annual probability of 10 per cent. This probability aligns with a likelihood score of B on the AusNet Services risk matrix. This likelihood is applied to the network performance risk caused by a conductor or ground wire functional failure. Not every major failure of a conductor or ground wire presents health and safety risk or bushfire ignition risk to the public; the event will have to occur under exceptional circumstances as discussed in section 3.4.6 and 3.4.7 below. The probability is very low and aligns with a likelihood score of A on the AusNet Services risk matrix.

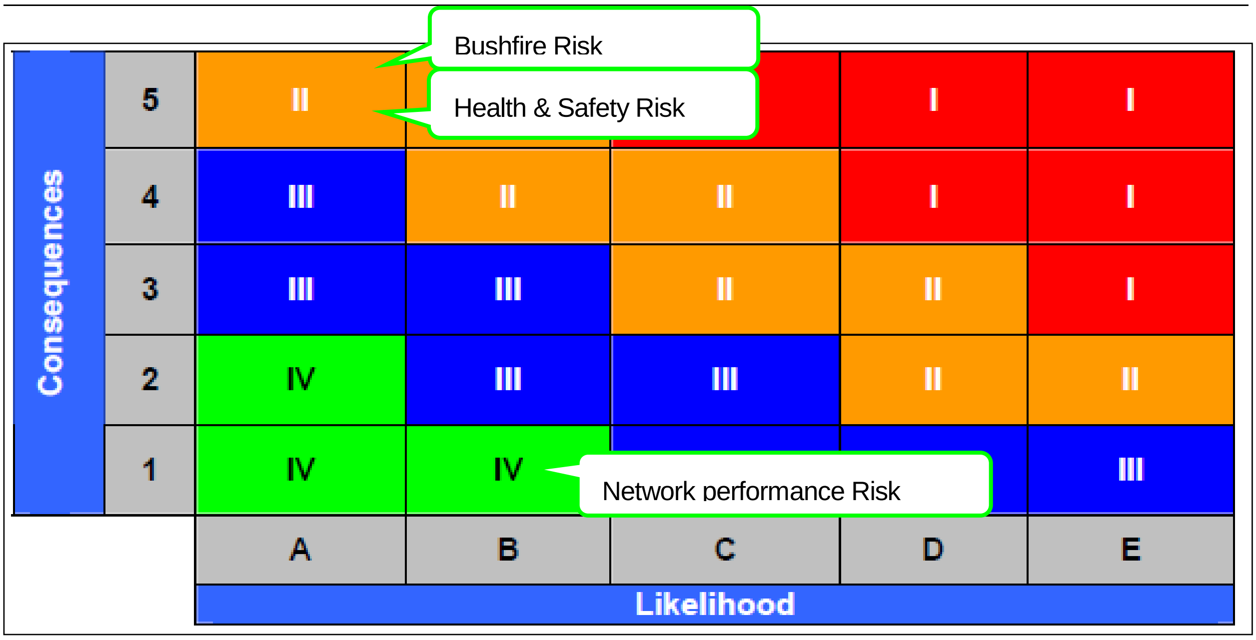


Figure 13 – AusNet Services' Risk Matrix[14]

3.4.6 Health and Safety

Transmission line easements traverse both public and private land where public access is restricted. In many instances easements are shared or cross other infrastructure such as roads, railway lines, pipes and fences.

Conductor and ground wire functional failures can present health and safety risks to members of the public, AusNet Services' employees or AusNet Services' contractors accessing the transmission line easements. These risks are especially apparent on structures across roadways or railway lines as high volumes of people are exposed.

Using the results of a study performed by Vic Roads[15] in 1994, a quantitative consequence assessment of transmission line spans which cross roads and railways has been completed. The assessment has revealed that a conductor or ground wire functional failure could cause a health and safety incident with a maximum risk rating score of II as per the AusNet Services' risk matrix.

There have been no instances of conductor or ground wire functional failures across roads or railways.

3.4.7 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[16] of Melbourne University has enabled the establishment of quantitative bushfire consequence values for transmission line assets. The bushfire loss consequence model demonstrates that a conductor or ground wire functional failure could trigger a bushfire incident with a maximum risk rating score of II as per the AusNet Services' risk matrix. A map displaying the bushfire consequences associated with transmission line assets is included in Appendix B.

There have been no incidents of bushfire ignition from conductor or ground wire assets on the Victorian transmission network.

[14] AusNet Services' Risk Management Framework – RM 001 2006.

[15] Bureau of Transport and Communications Economics (1994) - The Costs of Road Accidents in Victoria – 1988.

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

3.4.8 Network constraints

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.

The Australian Energy Market Operator's (AEMO's) availability incentive scheme (AIS) quantifies the impact of Victorian electricity transmission network constraints on the operation of the National Electricity Market. AusNet Services pay AEMO the economic value associated with removing specific network assets from service at specific times within the seasonal and daily load cycles. The AIS provides suitable economic values for inclusion in dependability models as the failure effect costs of critical assets.

Conductor or ground wire functional failures result in system outages which negatively impact on performance levels within the incentive schemes. Impacts on the schemes are compounded when failures take place on radial lines. Financial penalties likely to be imposed can be calculated using guidelines set out by the AER. These calculations indicate that a conductor or ground wire functional failure would result in a maximum financial penalty corresponding to a maximum risk rating score of IV as per the AusNet Services risk matrix.

3.4.9 External performance benchmarking

AusNet Services participated in the 2013 ITOMS performance benchmarking study. The survey enables a participating TNSP to compare its performance relative to other TNSP's based on service and cost levels.

AusNet Services ranked above the average performance of other Australian and New Zealand transmission utilities in terms of service level (measured in fault/forced outages per circuit km) and cost level (measured in equivalent maintenance costs per circuit km) for 200 kV+ transmission voltage categories. However, the cost level for the 60-99 kV category is slightly higher than the average performance of other Australian and New Zealand transmission utilities.

The survey indicates that the maintenance strategies and costs are appropriate for our network. Figure 14 and Figure 15 displays results in the 60-99 kV and 200 kV+ categories respectively.

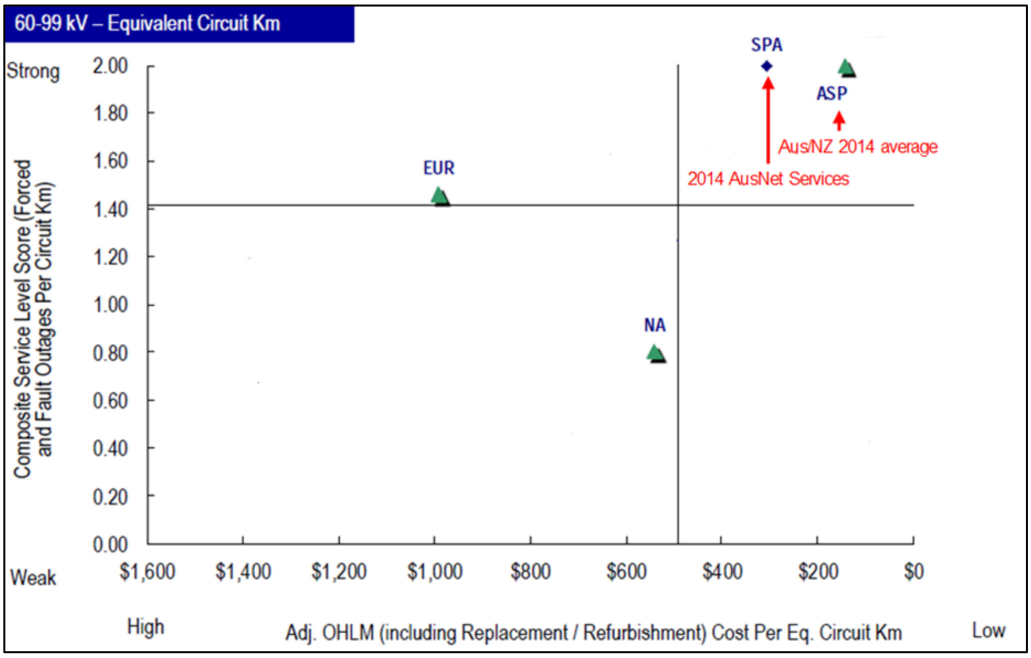


Figure 14 – ITOMS benchmarking 66 kV transmission lines

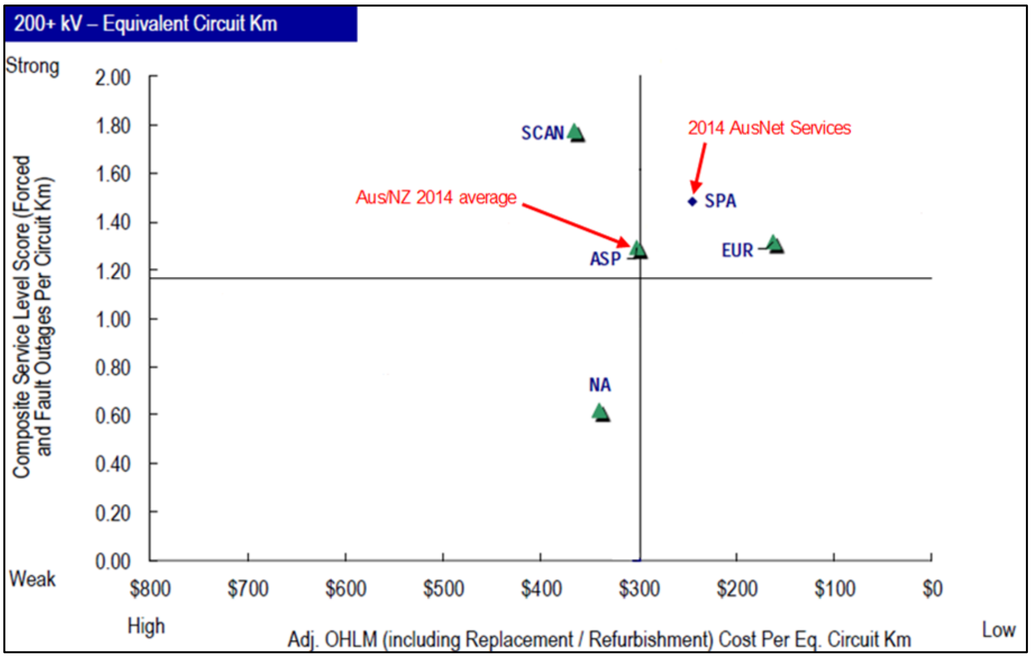


Figure 15 – ITOMS benchmarking 220 kV, 330 kV and 500 kV transmission lines

3.5 Ground Clearance Management

Early transmission lines built in Victoria were designed using English standards which specified a maximum operating temperature of 49^{o}C. Higher ambient temperatures in Victoria meant that this maximum operating temperature was reached at lower line loadings. This issue was addressed by the SECV in the early 1960's by increasing the maximum operating temperature to 65^{o}C and permitting lower ground clearances.

Energy Safe Victoria (ESV) endorsed AusNet Services' ESMS[17] in 2010, which included the remediation of substandard ground clearances in accordance with the requirements of the Electrical Safety (Management) Regulations to ensure that health and safety risks are reduced "So Far As Is Practicable"[18]. In practice this means safety risks should be proactively managed until the cost becomes disproportionate to the benefits.

In order to quantify risks associated with low clearance spans AusNet Services has performed Aerial Laser Surveys (ALS) of approximately 97 per cent of transmission lines on the network. Those transmission lines built to low operating temperatures and historic ground clearance requirements were given priority for ALS.

The results of ALS revealed that 80 spans have clearances below current design standards. More than 59% of these estimated clearance issues are expected to be less than 700 mm from current design standards.

The completion of the ALS program will be an important milestone and will provide AusNet Services with critical information required for the completion of a risk management plan by 2022. AusNet Services has already initiated the development of this risk management plan outlining steps required to reduce risks "So Far As Is Practicable".

The risk management plan considers key information such as the magnitude of the clearance issue, ground conditions below the span and the likelihood of contact with vehicles to establish the scope of the rectification works required. This information is also used to prioritise spans requiring corrective action. Typical rectification or mitigation actions depend on the risk; typical corrective actions include installation of signage and barriers, restricted access for vehicles over specified heights, prevent access for vehicles over certain heights and no access for any vehicles or persons.

[17] ESMS 20 01 - Overview for Electricity Transmission Network.

[18] Electrical Safety (Management) Regulations – Clause 11.2.(d).

3.6 Key Issues

The key issues associated with the transmission line conductor and ground wire fleet are as follows:

- Approximately 24 per cent of the conductor and ground wire fleet have been in service for more than 50 years[19], this figure is forecast to be to approximately 58 per cent by 2022.
- Steel ground wires are approximately 44 percent of the ground wire fleet; most of them are in service for more than 50 years and are approaching the end of life.
- Corrosion of transmission line conductor and ground wire is accelerated in some areas due to exposure to harsh environmental conditions which can reduce expected service life by more than 50 per cent.
- Four per cent of transmission line conductor and ground-wire spans are displaying established signs of corrosion and require remedial action within ten years.
- Functional failure of conductors and ground wire on spans crossing road or rail corridors present significant public health and safety risks.
- 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 which can improve the accuracy of condition data collected.
- Accurately assessing the condition of mid span sections of conductor and ground wire during tower climbing inspections is very difficult. More advanced technologies such as the application of the SAIP system can improve the accuracy of condition data collected.
- Transmission line conductor and ground wire condition data is collected via a paper based system and subsequently converted to electronic format. This process is labour intensive and out dated. Field Mobile Inspection (FMI) systems offer a more advanced and efficient approach to collation of a wide range of asset data including condition grades.

[19] The expected asset lives of conductors and ground wires at low, moderate, severe and very severe corrosivity environment are 80, 70, 40 and 30 years respectively.

4 Risk Assessment

This section discusses two separate risk assessments relating to the conductor and ground wire fleet. Reliability Centred Maintenance (RCM) techniques were used to guide the development of optimised asset replacement programs. A risk management plan has been developed, to reduce risk associated with conductor spans with inadequate clearance to ground.

4.1 Dependability Management

Dependability management methodology brings together asset condition data, asset failure rates and the cost impact of asset failure to determine an economically justifiable level of replacement. This section summarises the reliability modelling of conductor and ground wire fleet. It sums the probabilistic replacements and equivalent risk costs and identifies the economic replacements required to prudently maintain failure risks. Key inputs to this dependability process are asset condition, remaining service potential (RSP %), failure rate and the failure effects[20].

Similar to the approach taken by Tohohu Electric Power Service in Japan[21] conductor and ground wire condition assessments of the Victorian network have been used to determine Remaining Service Potentials (RSP) for different condition grades. RSP profiles replicate reductions in Ultimate Tensile Strength (UTS) for different condition grades.

Conductors and ground wires situated in the “very severe” and “severe” corrosivity zones have considerably shorter lifecycles when compared to assets in the “moderate” and “low” corrosivity zones. Dramatic reductions in useful life have been demonstrated by failure of ACSR on the HYTS- APD 500kV line in 2008 after 25 years of service.

Figure 16 displays a comparison of profiles for changes in RSP for different condition grades against reductions in UTS through time.

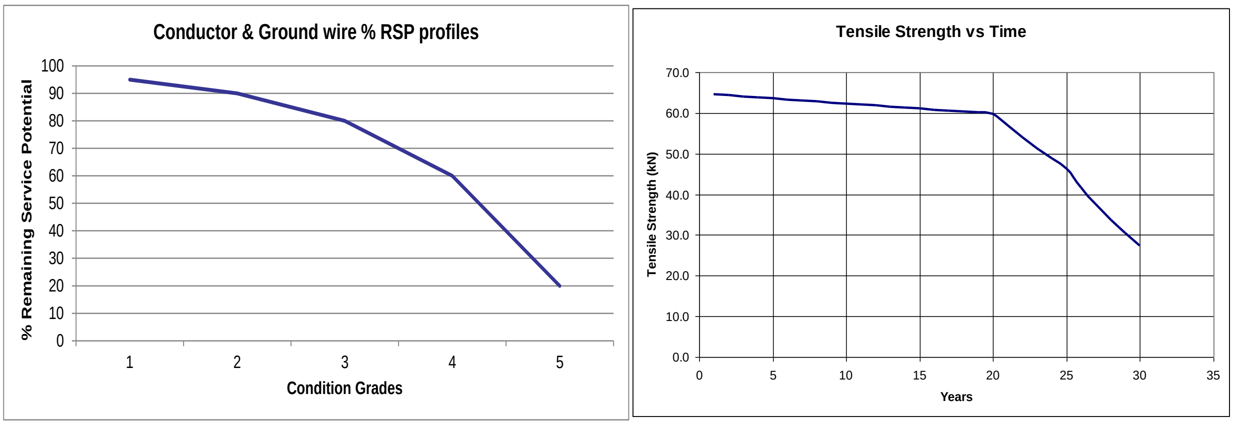


Figure 16 – Remaining Service Potential and Reduction in UTS over time

AMS 20-11 Dependability Management provides more detail on the dependability management methodology.

[20] Effect costs were calculated against each of the possible failure effects discussed in section 3.4.3 including health and safety, bushfire ignition and network performance. The total failure effect cost for each asset was taken as the sum of all failure effects.

[21] Cigre Paper B2_213_2012 Corrosion characteristics based on an investigation of sampled OHTL conductors and a probabilistic lifetime estimation method.

4.2 Scenarios

The dependability analyses for the ground wire and conductor fleet were performed in AWB software and excel spreadsheet respectively. Two fundamental scenarios are used in these analyses; run to failure and risk optimised.

4.2.1 Run to Failure Scenario – Ground wire

The run to failure scenario assumes that no preventative replacement of an asset or assets is undertaken. It calculates the minimum total life cycle costs, associated with corrective replacements following in-service failures, required to maintain service from the asset(s) over the modelling period.

A total life cycle cost of [C.I.C] comprising the Effect Cost (health and safety, bushfire ignition and network performance) and reactive ground wire replacement costs (labour, equipment and spare) are shown in **Error! Reference source not found.**.

[C.I.C]

Figure 18 shows that a run to failure strategy would result in a total effect cost of [C.I.C] over the next 10 year period. The effect cost is disproportionate to the replacement costs of approximately [C.I.C]. This effect cost is largely distributed between those assets assessed as in deteriorated condition; Condition 4 or Condition 5.

Over the next 10 year period, reliability modelling suggests that a run to failure strategy would result in 427 spans (approximately 171 km) of ground wire failures with associated replacement costs of [C.I.C] (labour, equipment and spare purchases).[22]

The run to failure scenario does not represent the minimum life cycle cost and is subsequently not recommended as an efficient use of limited resources or the most prudent investment for customers.

This scenario is not the most prudent investment for customers and is presented here for comparison with a risk optimised scenario described in the section below.

[22] The model assumes condition score C1 (as new) for approximately 79km of ground wires on the KTS-WMTS and KTS-GTS No.2 220 kV lines, which will be replaced under an approved project XC77 over the period of 2014/15 to 2016/17.

4.2.2 Risk Optimised Scenario – Ground wire

The risk optimised scenario selectively replaces assets in a planned manner wherever the costs of planned replacement are less than the effect costs associated with an asset failure within the selected planning period.

The effectiveness of the proposed preventative maintenance activity in increasing asset availability by reducing outage frequency or down time can be compared with that of the default strategy of running the asset to failure and then undertaking corrective maintenance. Similarly the relative efficiency of the proposed preventative maintenance can be measured by comparing its costs with those of the corrective maintenance.

Error! Reference source not found. shows a [C.I.C] total life cycle cost for the risk optimised management of ground wires over the next ten years. It shows a significant [C.I.C] reduction in the total impact on customers and replacement costs compared with the run to failure scenario.

[C.I.C]

Error! Reference source not found. shows selective replacement of 890 ground wire spans (approximately 356 km) in Condition 2, Condition 3, Condition 4 and Condition 5, will increase replacement costs from [C.I.C] over the ten year period and provide a significant reduction in the impact on customers from [C.I.C].[23]

Reliability modelling demonstrates that a Risk Optimised Scenario is the most economic use of limited resources and provides a significantly lower life cycle cost to customers.

[23] The model assumes condition score C1 (as new) for approximately 79 km of ground wires on the KTS-WMTS and KTS-GTS No.2 220 kV lines, which will be replaced under an approved project XC77 over the period of 2014/15 to 2016/17.

4.2.3 Run to Failure Scenario – Conductor

A total life cycle cost of [C.I.C] comprising the Effect Cost (health and safety, bushfire ignition and network performance) and reactive conductor replacement costs (labour, equipment and spare) are shown in **Error! Reference source not found.**.

[C.I.C]

Error! Reference source not found. shows that a run to failure strategy would result in a total effect cost of [C.I.C] over the next 10 year period. The replacement costs of approximately [C.I.C]. This effect cost is largely distributed between those assets assessed as in good condition; Condition 2. Only one percent of the total lifecycle cost is generated from assets in Condition 5 (very poor).

Over the 10 year period, reliability modelling suggests that a run to failure strategy would result in 233 spans of conductor failures associated replacement costs of [C.I.C] (labour, equipment and spare purchases) over the 10 year period.

Ninety nine percent of the conductor fleet is in Condition 1 to 3. AusNet Services is managing the risk for those assets in Condition 1, 2 and 3. The remaining one per cent of the conductor fleet is primarily in Condition 4. SAIP is to be used as part of preventative maintenance strategies for the early identification of issues and defects. This improved assessment techniques offer a higher degree of confidence in predicting the extent and optimal timing of future replacements.

As conductor replacement costs are high and given the total lifecycle cost for conductor 4 and 5 are relatively low, deferral of replacement works based on improved condition assessments is considered prudent.

4.2.4 Replacement Forecast

AusNet Services has applied optimised RCM risk modelling techniques to the entire conductor and ground wire fleet in order to establish a prioritised replacement program. This approach has employed probabilistic risk modelling techniques to establish a targeted and economic replacement program.

4.2.5 Ground wire replacement forecast

Dependability model recommends selective replacement of 890 ground wire spans (approximately 356 km) in Condition 2, Condition 3, Condition 4 and Condition 5 over the ten year period.[24] AusNet Services is managing the risk for those assets in Condition 2 and 3, and replacement is deferred where deemed appropriate.

The dependability model shows that material risks are generated from the Condition 4 and 5 steel ground wires. The steel ground wires are the oldest ones in service, they are reaching end of life in areas where corrosion rates are high. This is generally in areas of industrial pollution in the Latrobe Valley and Metropolitan Melbourne and any coastal areas. These issues are compounded by high failure effect costs for conductors spanning roads and railways or situated on circuits which impact heavily on incentive scheme performance measures.

There is an approved project (XC77) to replace approximately 79 km of ground wires on the KTS-WMTS and KTS-GTS No.2 220 kV lines by 2017. An additional 226 km ground wires are forecast for replacement before 2022.

4.2.6 Conductor replacement forecast

Ninety nine percent of the ground wire fleet is in Condition 1 to 3. AusNet Services is managing the risk for those assets in Condition 1, 2 and 3.

The remaining one per cent of the conductor fleet is predominantly in Condition 4. SAIP is to be used as part of preventative maintenance strategies for the early identification of issues and defects. It is expected that small number of defective conductors will require replacement or repair as part of corrective maintenance tasks.

No conductor is forecast for replacement before 2022.

[24] The model assumes condition score C1 (as new) for approximately 79 km of ground wires on the KTS-WMTS and KTS-GTS No.2 220 kV lines, which will be replaced under an approved project XC77 over the period of 2014/15 to 2016/17.

5 Strategies

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

5.1 New Assets

- All newly installed conductors are designed and constructed in accordance with current industry guidelines and standards[25].
- Replace ground wires with OPGW where required for communication purposes.
- AAAC is more corrosion resistant than ACSR and is suitable to be used in area subjected to extreme corrosivity to ensure maximum life.

5.2 Inspection

- Adapt the use of Smart Aerial Image Processing (SAIP) technology to assess the condition of conductor and ground wire. 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.
- Complete Aerial Laser Surveys (ALS) using LIDAR laser technology on the remaining three per cent of transmission lines by 2022.
- Implement the use of the Field Mobile Inspection (FMI) system as the primary means of capturing condition assessment data. The FMI system must be designed to update the transmission asset management system as part of automated process.

5.3 Maintenance

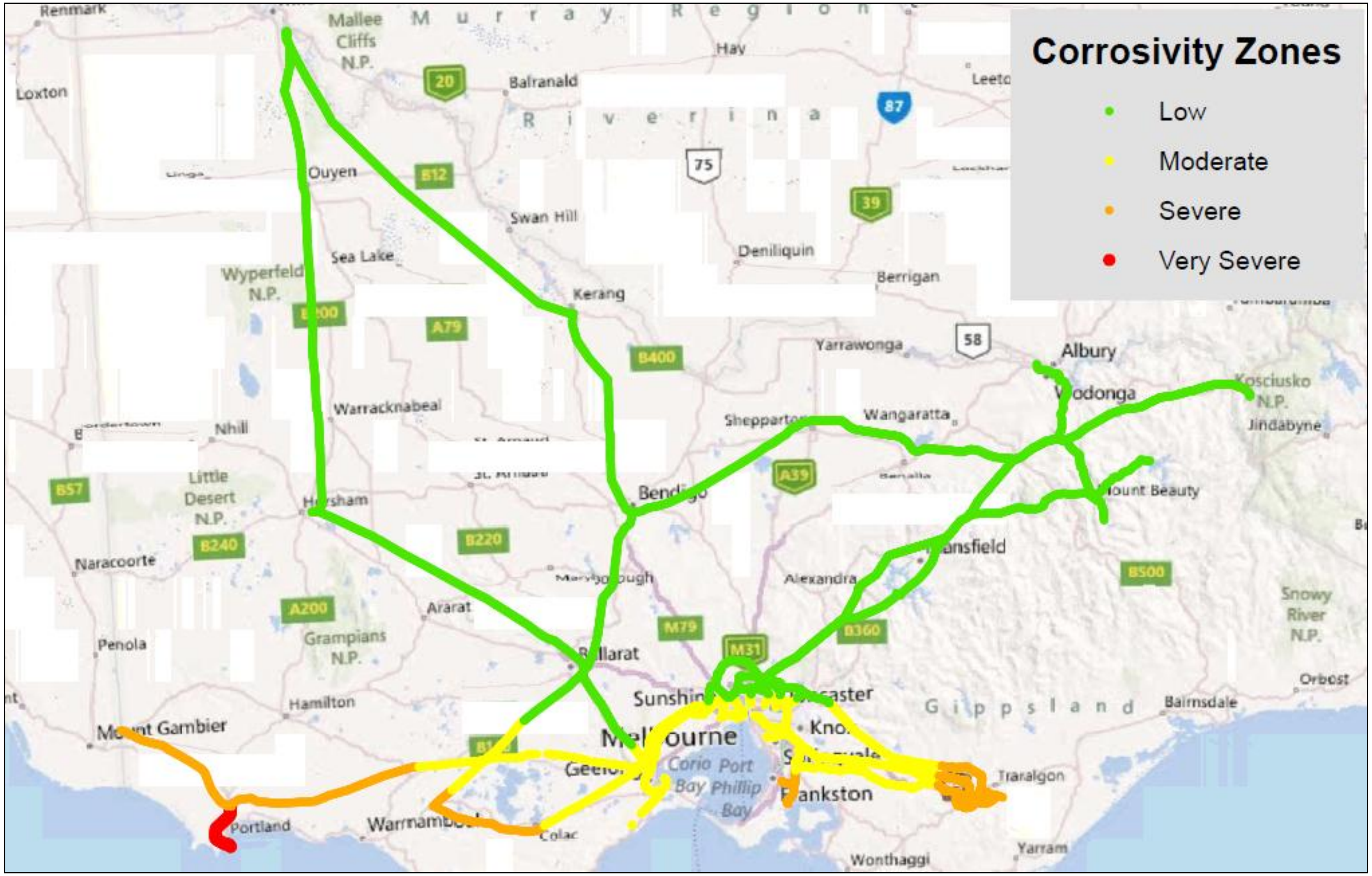
- Replace or repair defective conductor and ground wire assets as part of corrective maintenance tasks.
- Develop and implement a risk management plan for all transmission line spans identified as not meeting current design standard by 2022.

5.4 Replacement

- There is an approved project (XC77) to replace approximately 79 km of ground wires on the KTS-WMTS and KTS-GTS No.2 220 kV lines by 2017.
- Replace additional 226 km of ground wire (three per cent of the ground wire fleet) which have been deemed economically justified for replacement by April 2022. Ground wire replacements will address the highest risk spans as a priority.

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

Appendix A – Corrosivity Zones on the Victorian Transmission Network



Appendix B – Bushfire Consequences on the Victorian Transmission Network

[C.I.C]