AMS 10-77 Transmission Line Structures

2023-27 Transmission Revenue Reset

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1 Executive Summary

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

There had been 45 structure functional failures associated with eleven extreme wind events affecting this transmission network since 1959. All failed structures were built to historical design standards with inadequate strength to withstand convective downdraft winds occurring during extreme storm events. Modern design standards produced in 2010 ensure sufficient structural capacity to withstand extreme wind events; however, structures designed to old standards still exist on the network.

The mean time between failures (MTBF) of transmission line structures has declined since 1992 due to failures of low-strength towers in extreme winds. Eleven structures along the Bendigo to Kerang line were replaced in January 2013, as well as reinforcement on 108 towers from the Dederang to South Morang 330 kV lines. Risk assessments reveal that 60 structures on the Murray Switching Station to Dederang 330 kV lines present health and safety risks due to their proximity to roadways and will be upgraded before 2022. The latest tower collapse event occurred early this year in one of the 500 kV circuits built 40 years ago, which is located along an open and flat terrain in the South West part of the network. The 7 permanent structures are scheduled to be installed later this year.

The average age of structures is 50 years as majority of the fleet were erected prior to 1965. Primary inspection techniques indicate that the structures are generally in good condition.

The structure corrosion management program is extending the life of targeted structures where replacements are impracticable due to high cost and prolonged circuit outages. Typical corrosion mitigation works include structure painting and replacement of bolts and members.

Four structures along the Heywood Terminal Station to Alcoa Smelter at Portland, Victoria will be replaced with new structures due to the heavy corrosion that has affected the tower members and bolts. The new structures will be designed to the latest tower code, AS/NZS 7000.

The Fall Arrest Systems (FAS) will be installed on structures which will have other programs done on them such as insulator replacement, conductor replacement, and groundwire replacement. This will ensure the Occupational Health and Safety Regulations are met as well as follow the risk management philosophy of minimising personnel risks to "As Low As is Reasonably Practicable."

High level strategies to be adopted for prudent and efficient management of the transmission structure fleet are:

1.1 New Assets

- All new structures are designed and constructed in accordance with current industry guidelines and standards[1].

1.2 Inspection

- Continue to assess the condition of transmission line structures during structure detail inspections which are conducted at 3-, 6- or 9-yearly intervals.
- Implement the use of Field Mobile Inspection (FMI) technologies for the collation of condition assessment data which facilitate automatic updates of Asset Management databases.
- Explore and introduce new technologies in performing structure inspections to improve the effectiveness, productivity, and safety of workers.

[1] AS/NZS 7000:2016 Overhead Line Design – Detailed Procedures.

1.3 Maintenance

- Continue to replace corroded or damaged steel members and bolts as part of corrective and scheduled maintenance programs.
- Continue to perform corrosion mitigation works on corroded structures, specifically on towers along HYTS-APD 500 kV, ROTS-SVTS 220 kV, SVTS-HTS 220kV, and poles along MWTS-LY 66 kV circuits.
- Perform fleet wide risk assessment to identify corrosion mitigation works based on the structural strength, corrosivity zone and failure effects.
- Use the emergency restoration structures (ERS) to temporarily reinstate a line impacted by high intensity winds.

1.4 Spares

- Continue to maintain sufficient strategic spares Transmission Line structures and associated hardware.

1.5 Refurbishment

- Continue to install Fall Arrest Systems (FAS) on remaining structures by including the installation into the scope of projects; approximately 78 percent of the tower fleet will be retrofitted with FAS by 2022.
- Complete the installation of FAS on all rack structures and groundwire masts in terminal stations by 2028.
- Perform structural modelling of existing structures as part of tower upgrades and other lines projects, e.g. conductor and groundwire replacement projects.

2 Introduction

2.1 Purpose

The purpose of this document is to define the asset management strategies for the Victorian electricity transmission network's population of transmission line structures.

2.2 Scope

This asset management strategy applies to all transmission line structures associated with the AusNet Services' regulated asset base belonging to the electricity transmission network that operate at voltages of 66 kV and above in the state of Victoria. The strategy applies to structures situated on lines easements, as well as towers and termination structures also known as rack structures within stations.

The strategy excludes structure footings[2], structures supporting stations assets, assets forming the electricity distribution network, communication towers or masts, and those belonging to AusNet Services' unregulated asset base.

The strategies in this document are limited to maintaining existing equipment performance. 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.

[2] AMS 10-78 Transmission Line Structure Footings

3 Asset Description

3.1 Asset Function

Transmission line structures help transport power within the network while assuring its reliability and keeping the public and environment safe, by supporting the phase conductors and groundwires at a safe distance from the ground, structures, and vegetation.

Transmission structures are made from engineered or manufactured components which provide reliability and durability throughout its service life. Most common structures are made from lattice or tubular steel, with only a minor portion made from reinforced concrete or timber (wood).

3.2 Asset Population

There are approximately 13,000 transmission line structures in service on the transmission network. Structures comprise all elements above 300 mm above ground-level, which support the conductors and ground wires. Different types of structures in service include steel lattice structures, poles, rack structures and ground wire masts. Figure 1 displays the number of different types of structures by operating voltage.

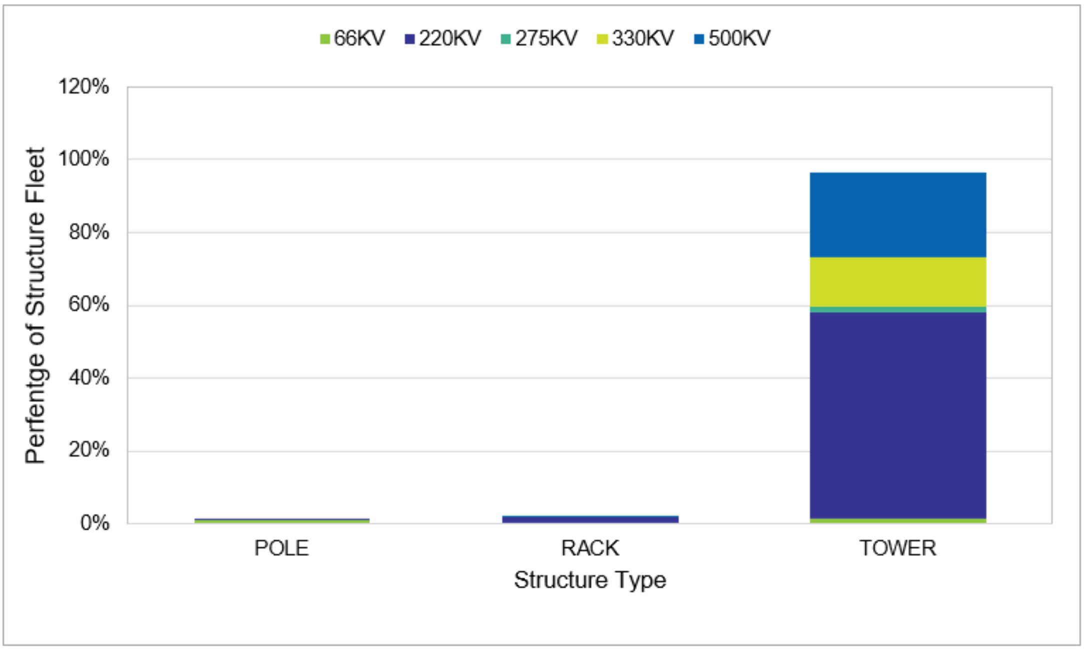

Figure 1 – Volumes of structures by type and voltage

3.2.1 Towers

Steel lattice structures make up approximately 97 per cent of structure types on the transmission network. Lattice structures consist of angled galvanised steel members connected with bolts. These structures generally support either single-circuit or double-circuit lines including three different phase conductors[3] per circuit. The phase conductors are protected from lightning strike by single or multiple ground wires[4] situated on the peaks of the structures. Some structures support subsidiary distribution lines operating at 66 kV situated below the

[3] AMS 10 – 79 Transmission Line Conductors.

[4] AMS 10 – 79 Transmission Line Conductors.

transmission circuit phase conductors. The structures are electrically insulated from the live conductors using insulators[5]. Figure 2 displays an image of a typical steel lattice structure (500 kV single circuit delta suspension).

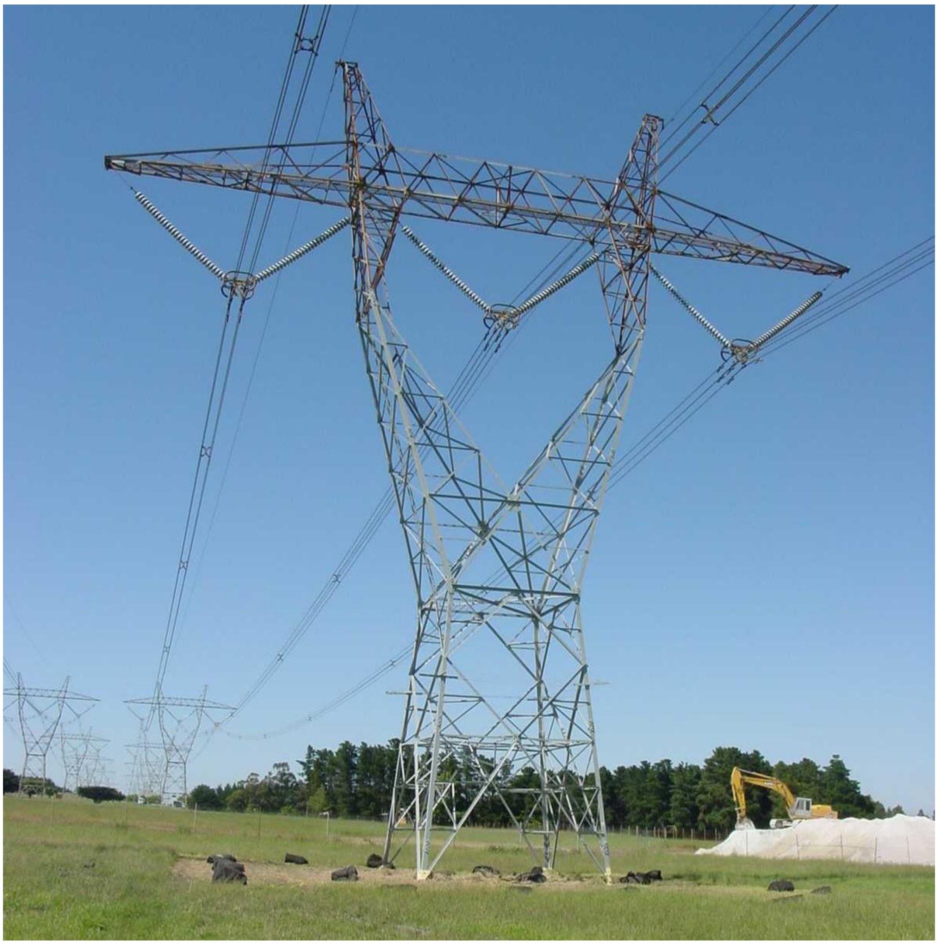

Figure 2 – Transmission Line Structure

3.2.2 Rack Structures

Racks comprise 4% of the total population of the transmission structure fleet. The primary function of rack structures is to facilitate the transition of phase conductors from line easement structures to electrical plant situated in terminal stations. Rack structures consist of steel lattice members connected by fasteners or tubular hollow sections bolted or welded together. The majority of rack structures are situated within terminal stations; however, there are a number of rack structures known as portal structures which are situated within line easements.

Portal structures are designed to accommodate acute changes in line easement alignment such as 90-degree tee offs or in some cases when a line transitions as an under-crossing line. Rack and portal structures make up two percent of the total structure population. Figure 3 displays a transmission line rack structure at Dederang Terminal Station (DDTS).

[5] AMS10 – 75 Transmission Line Insulators.

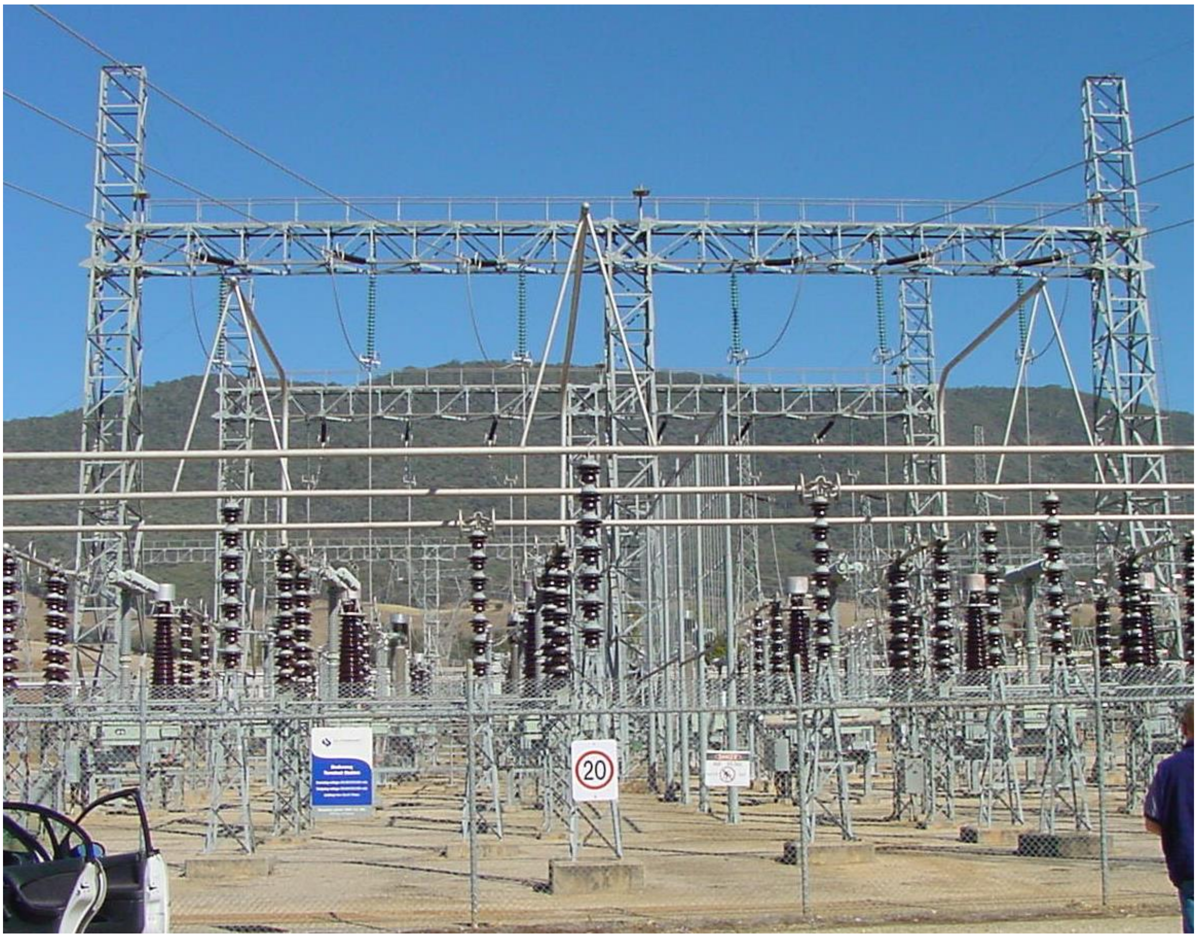

Figure 3 – Transmission Line Rack Structure

3.2.3 Poles and groundwire masts

Steel, concrete and wood poles, which comprise 1% of the fleet, are used on the transmission network usually to support phase conductors over short distances. Transmission line poles are generally situated in close proximity to terminal or power stations in the La Trobe Valley. Fifty-two percent of transmission line poles support circuits operating at 66 kV while forty two percent support circuits operating at 220 kV. There are approximately 60 ground wire masts located within terminal stations, these are steel lattice structures designed to protect electrical plant and infrastructure from lightning strike.

3.2.4 Design Characteristics

Transmission structures are further categorised based on design characteristics. The design characteristics determine what mechanical load the structure can support. There are five design categories including heavy strain (HST), light strain (LST), heavy suspension (HSU), light suspension (LSU) and transposition (TRN). Figure 4 displays the proportion of the structure fleet within each design category by operating voltage.

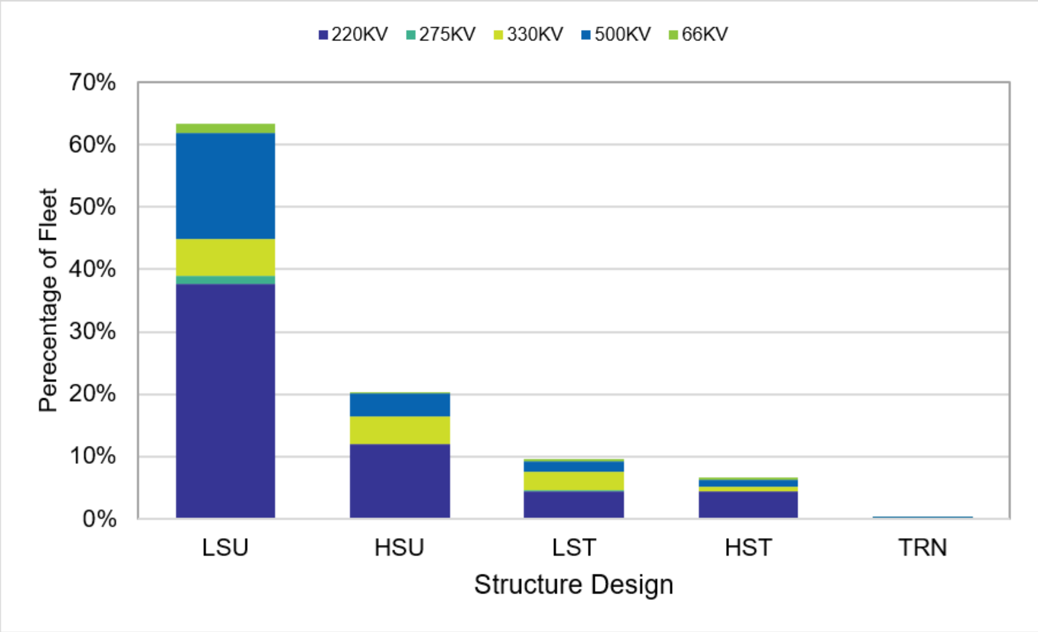

Figure 4 – Volumes of structures by design category and voltage

Strain structures carry a combination of vertical and horizontal loads from conductors and its ancillary hardware. These structures allow conductors to be terminated or strained off with the structures in line with the conductor axis. Light strain structures (9% of structure fleet) are used where there is a moderate turn-off angle in the circuit or where additional support is required to reduce risks such as those at road and rail crossings. Heavy strain structures (7% of fleet) contain more reinforcement when compared to light strain structures. Heavy strain structures are used before circuits enter or exit from terminal or power stations. These structures are also used along line easements with large turn off angles.

Suspension structures carry vertical loads from conductors and its ancillary hardware, ensuring that ground clearance requirements are met between strain structures. Light suspension structures make up 63% of the total structures fleet. This design type is used when there is moderate, or nil turn off angle in the circuit easement alignment. Heavy suspension structures (20%) are designed to carry more vertical loads and longer conductor spans when compared to the light suspension cohort. These structures are also used for large circuit easement deviations.

Transposition structures (0.2%) are required to balance the impedance of circuits which traverse long distances. The process of transposition is required to ensure that network voltages are balanced adequately. Transposition is achieved by interchanging the phase conductors of the circuit at one third increments of the total line length.

The 330 kV strain tower, 220 kV suspension tower and 500 kV transposition tower are shown in the following figures 5,6 & 7.

Figure 5 - DDTS-SMTS No. 1 330 kV strain tower

Figure 6 - ROTS-SVTS 220 kV suspension tower

Figure 7 - HWTS-CBTS No. 4 500 kV transposition tower

3.2.5 Environmental Factors

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

Figure 8 shows the percentage volume of transmission structures located in each of the three corrosivity zones. A map displaying a spatial view of transmission line assets within the four corrosivity zones is included in Appendix A. Fifty-two percent of structures are situated in the low corrosivity zone, while forty-seven percent are in moderate corrosivity zone. The last few towers of the HYTS – APD 500 kV lines are situated in the severe corrosivity zone as they supply power to an Aluminium smelter plant situated at Portland on Victoria's south-western coast.

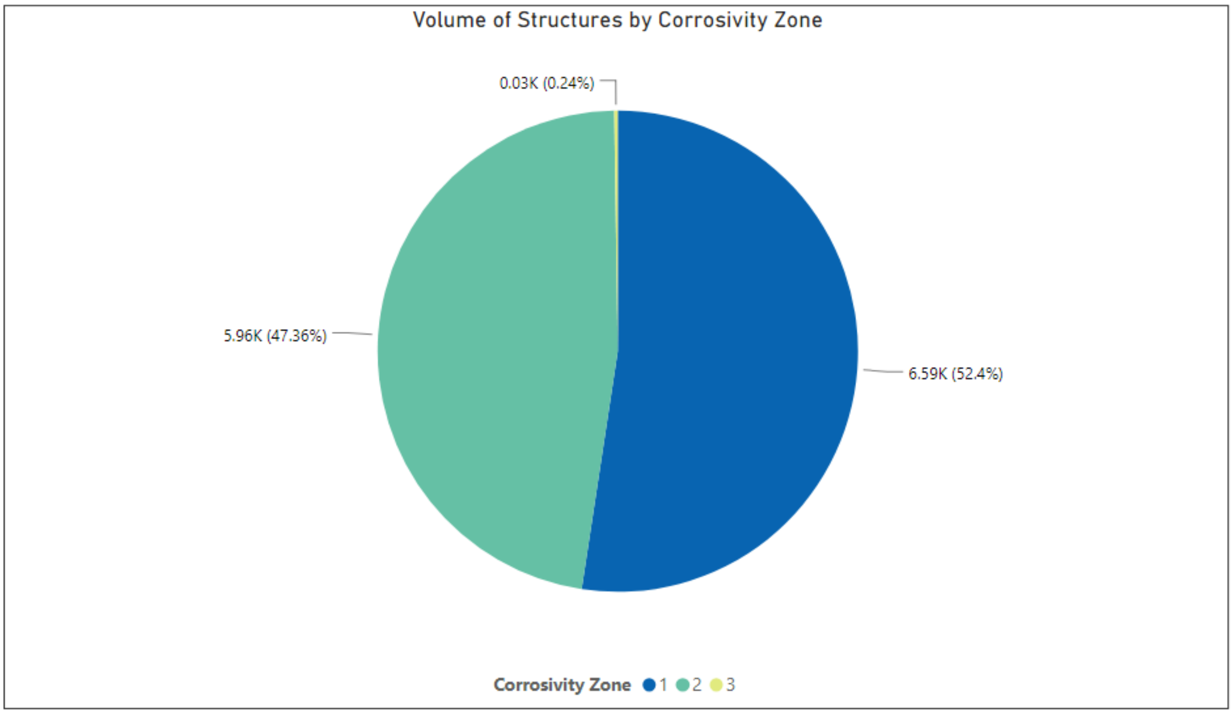

Figure 8 – Volume of structures by corrosivity zone

3.3 Age Profile

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 Latrobe Valley. Construction of 220 kV lines first began in 1950. Connections to the New South Wales network was later achieved via 330 kV lines built between the late 1950's and early 1980's. 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 average structure age is given in Table 1. The average age of the transmission line structure population is about 53 years.

Table 1 – Average Structure Age by Voltage

Voltage Class	Average Age
500 kV	41.4
330 kV	52.0
275 kV	31.0
220 kV	53.6
66 kV	43.3
Overall Avg.	**52.6**

Figure 9 displays the service age profile of transmission line structures by voltage class. The structure service age profile roughly reflects that of a normal distribution with a mean age of approximately 45 years. The expected service life of AusNet Services towers is 70 years.

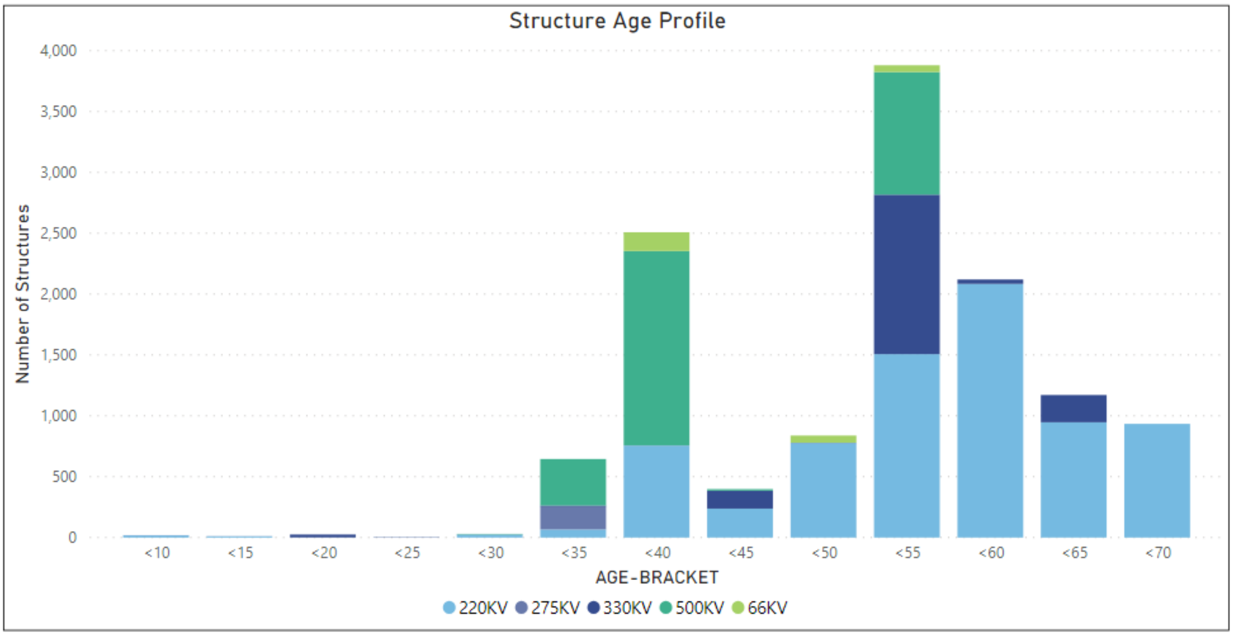

Figure 9 – Structure Service Age Profile

3.4 Asset Condition

3.4.1 Condition assessment

Condition of transmission line structures is assessed during regular detailed inspections which are conducted at 3, 6 or 9 yearly intervals, depending on the criticality of the line asset (e.g. structure, insulator, conductor and groundwire) at that location.

Structure members and bolts are assigned a condition grade from a scale between C1 and C5. Table 2 outlines condition grades for structure members and bolts including a description against each different grading parameter. More detail is described in LPP 09-06: Condition Assessment of Overhead Lines.

Table 2 – Bolt and member condition grades and descriptions

Condition Scoring Methodology				
Condition Score	**Condition Description**	**Bolt & nut**	**Steel member, brace or steel poles**	**Remaining Life**
C1	Very Good	Good condition	Good condition	95%
C2	Good	First rust spots appear	First rust spots appear	85%
C3	Average	Patchy rust	Patchy rust	60%
C4	Poor	Large areas of rust or minor section loss	Extensive surface rust	25%
C5	Very Poor	Flaking and metal loss, functionality almost gone	Pitting or minor section loss	15%

Condition grades of structures are considered along with other factors such as age, type, corrosivity, effects of functional failures and structure loading design when taking decisions with respect to management of the asset.

Figure 10 shows the overall condition grades of transmission line structures per voltage rating. The rating for each structure is calculated by taking into consideration the condition grades given to the members and bolts, together with the extent of the corrosion present in each sub-component.

Eighty-six percent of structures are exhibiting condition grades of C1 or C2 indicating that they are in very good or good condition, while 12% of structures have been assessed as C3 condition, 1.5% percent have been assessed at C4, while none are in C5.

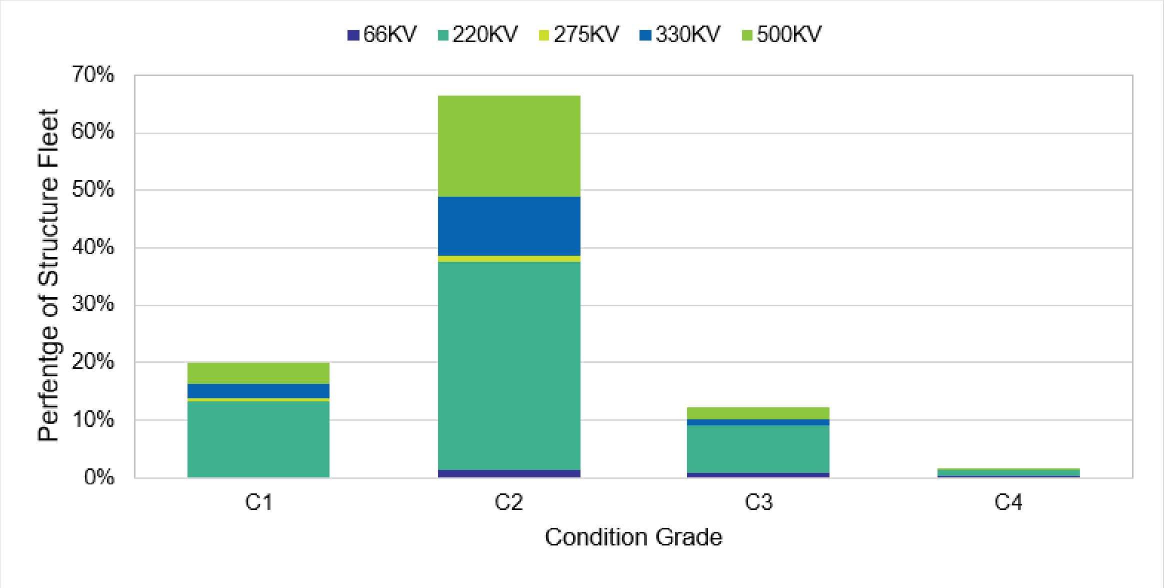

Figure 10 - Structure Condition Profile

3.4.2 Structure Condition vs Corrosivity

Figure 11 shows presents the over-all condition of the structure fleet spread across the three corrosivity zones in the transmission network. Structures in the low corrosivity area (Corrosivity Zone 1) are mostly in C1 and C2 condition, while majority of structures in medium corrosivity area (Corrosivity Zone 2) have assessed to be in C2 condition, with only a small percentage in C3 condition. Structures located in the high corrosive environment (Corrosivity Zone 3) are equally spread between C3 and C4 condition – mostly because these structures were painted almost 20 years ago. No assets have been assessed to be in C5 condition.

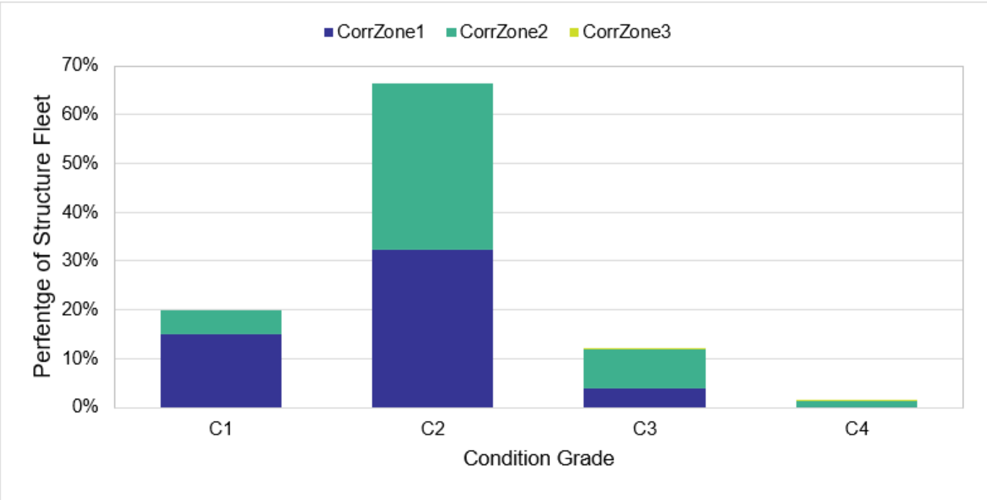

Figure 11 – Structure Condition vs Corrosivity Zone

3.4.3 Structure Condition vs Age

Figure 12 shows the condition of the tower fleet across its service life. C1 condition structures are almost evenly spread across service age brackets 35 years to 65 years, while C2 condition structures are mostly around the 55-year service range. Majority of C3 assets are more than 55 years old while C4 assets have had more than 55-years' service life with the exception on the HYTS-APD structures which are 40 years old.

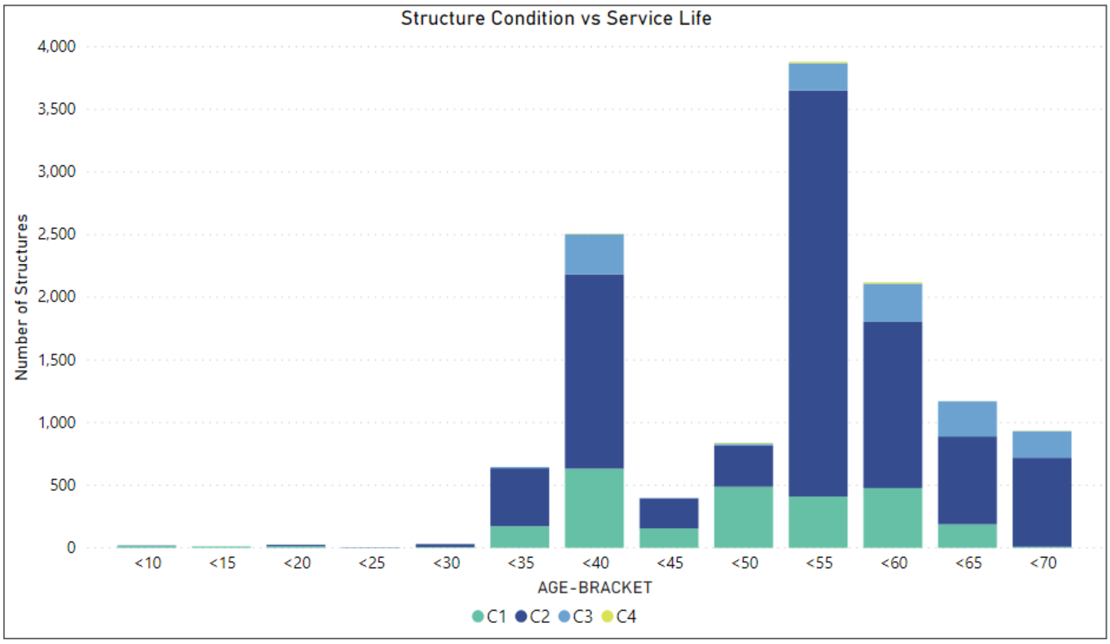

Figure 12 – Structure Condition Grades across Service Life

3.5 Asset Criticality

The consequence of failure of a transmission line structure can result in structures and live conductors falling to the ground with significant effects or consequences. The consequence can be categorised into five bands based on its economic impact. These discrete groups called asset criticality bands are independent of the structure's likelihood of failure.

The economic impact is calculated by adding these components:

- Bushfire ignition
- Health and safety
- Value of unserved energy/ Market impact
- Collateral damage

3.5.1 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 easement 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. The bushfire loss consequence model demonstrates that functional failure of a transmission line structure could trigger a bushfire incident with a risk ranking 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.

[6] A Bushfire Risk Assessment for the SP-AusNet HV Network in Victoria 2011.

There has been one incident where a structure failure has triggered a small ground fire. In 1981, a ground fire ignited following a structure collapse on the Murray switching station to Dederang 330 kV No.2 line caused by extreme winds during a storm event. The fire was relatively smaller in size and was extinguished by rainfall during the storm event.

3.5.2 Health and Safety Impact

Transmission line easements traverse both public and private land and in many instances, these are shared or located next to other infrastructure such as roads, railway lines, pipes and fences.

Line workers performing structure climbing activities are exposed to risks associated with working at heights and electrical clearances which are heightened under failure conditions. Structural failures may also present risks to members of the public, particularly with structures adjacent to roadways, railway lines and public areas such as car parks, parks and gardens.

Using the results of a study performed by Vic Roads[7] in 1994, a quantitative consequence assessment of transmission line spans which crosses roads and railways has been completed. The assessment has revealed that a major insulator failure could cause a health and safety incident with a maximum risk rating score of II as per the AusNet Services risk matrix.

Easement use types are categorised as urban, rural developed and rural undeveloped. Urban easement segments traverse over built-up private properties and on the other end of the spectrum, rural undeveloped easements are bare country properties. The health and safety consequence of a structure failure resulting to a tower collapse event has been calculated for each easement type.

On the last day of January 2020, a downburst wind event during a heavy thunderstorm that traversed Cressy, Victoria caused six- 500 kV structures, T138 to T143 to fail at ground level and collapse to the ground, while causing serious damage to T137. The conductors and groundwires of T138 pulled on T137, which is adjacent to an arterial road, and caused it to twist and bend. It was reported by a road user who drove under the line as the storm hit, that a blinding light, probably lightning, caused him to lose sight temporarily, prior to seeing a hay bale fly in front of his vehicle carried by the strong wind.

The existing tower upgrade project, TD-5956 has targeted structures in proximity to roadways that have inadequate strength to withstand high intensity winds.

3.5.3 Unserved Energy / 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.

The Australian Energy Market Operator (AEMO) conducts a study which identifies the amount customers are willing to pay to assure the reliability of their supply. This amount, called the Value of Customer Reliability (VCR), is used to monetise the consequence of the terminal station not being able to provide the load demand by the market, called the Value of Unserved Energy (VUE).

Another impact of lines becoming out of service is the need for AEMO to re-dispatch energy from a different generator (usually a gas generator) due to a line fault that either impacts the line directly, i.e. line is out of service so connected generator can't export energy to the market, or indirectly, i.e. the line outage constraints a certain part of the network so AEMO has to source power somewhere else to meet the load demand.

Structure functional failures will result to circuit outages which negatively impact on performance levels within the incentive schemes. Impacts on the schemes are compounded when major failures take place on radial lines or cause constraints on electricity generation. Financial penalties likely to be imposed can be calculated using guidelines set out by the Australian Energy Regulator (AER).

3.5.3 Collateral damage to adjacent AusNet Services towers/assets

The electricity transmission network was built in stages, using technical standards that were current on that period.

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

Over time built on improved knowledge and industry practice, technical standards are updated to become more appropriate to the weather events, e.g. wind and snow loads, as well as construction and maintenance loads structures and its components will support, e.g. out-of-balance loads, broken conductor loads, etc.

This situation means that assets built using older standards are more susceptible to fail in multiples, especially if these are connected in series, e.g. when a high wind event results to multiple collapsed towers.

The consequence of this event has been monetised by considering the design standards at the time of the asset's construction, and the potential damage inflicted on adjacent assets if it fails.

3.5.3 Damage to Third Party Property

Third party damage considers the consequence of a structural failure resulting to a tower, conductor and groundwire on the ground. The consequence depends on the easement use which are categorised as urban, rural developed and rural undeveloped.

Urban easement segments traverse over built-up private properties and/or councils while on the other end of the spectrum, rural undeveloped easements are bare country properties. The damage to properties, e.g. fence, roof, shed, swimming pool, tennis courts, etc. owned by third parties have been calculated for individual spans and used in the analysis.

3.5.4 Overall Criticality

The consequences of a structural failure can be allocated into five criticality bands based on their economic impact as the result of the failure. These asset criticality or consequence impacts are irrespective of the likelihood of the actual failure.

The five criticality bands are tabulated given in Table 3:

Table 3 – Criticality Band

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

The criticality assessment compares calculated consequence cost with replacement cost. Refer Table 5 Section 5.2 for the criticality-condition risk matrix for the structure fleet. The numbers indicate the quantity of structures which are under a specific condition score and have a consequence of failure within a specified Criticality Band.

3.6 Performance

3.6.1 Suspended failures

Defects that are detected and repaired before they cause a functional failure (i.e. circuit outage) are defined as a suspended failure. Suspended failures are also referred to as "preventative maintenance" actions in IEC 63000 terminology.

AusNet Services adopts a strict line patrolling and line inspection policy which objectively assesses the condition of transmission line components and identifies those assets which are no longer fit to remain in service. Components of transmission line structures deemed not fit for service are replaced by raising ZA Notifications ("NOTIs") in the Enterprise Asset Management System, SAP, using the mobility devices of the line crews.

Over the last six years there have been a total of 1,512 suspended failures of structure components. Typical suspended failures include bent or missing members and corroded, exploded or missing bolts. The first spike of suspended failures in 2015 represents the outstanding maintenance items carried across from the old Asset

Management System, MAXIMO 5 into SAP. Since 2016, the number of suspended failures has remained consistent at an average rate of 207-NOTIs per annum[8] as shown in Figure 13.

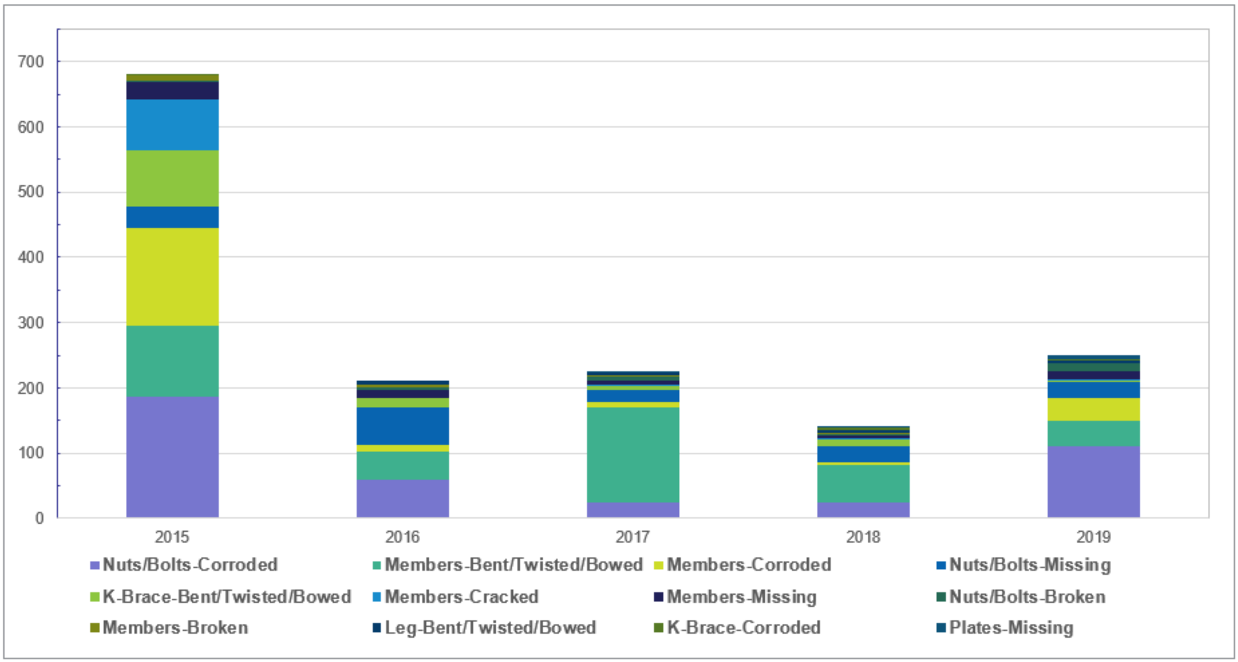

Figure 13 – Structure suspended failures

Forty one percent of suspended failures on transmission structures were associated to corrosion on bolts and members. Of this 41%, bolt corrosion represents 35% while member corrosion is 65%. Bolts are susceptible to corrosion due to the damage on the zinc layer during tightening works at construction, while the underside of steel angles that don't get exposed to the sun have the tendency to retain moisture, dirt, dust and salt which exacerbates corrosion.

Damage to steel members and legs such as bent, bowed, etc. represent 44% of suspended failures for transmission structures. Root causes of bent or damaged members include impact from vehicles or farming machinery, third parties using the tower's lower sections to support their equipment, stack items, etc. Bracing members can buckle or bend due to the imposition of loads beyond their design strength. Fortunately, majority of these incidents can be withstood by the structure due to the redundant nature of the bracing designs.

The balance of fifteen percent of suspended failures are attributed to missing members and plates due to vandalism and theft. Although all transmission line structures are fitted with anti-climbing barriers which act as deterrent for unauthorised access, the lower parts of the structures are vulnerable to theft due to the isolated nature where these assets are installed. In these very rare events, the Land Management Group of AusNet Services conducts community drives to engage the public and request assistance to secure the assets and report any suspicious activities to the proper authorities.

3.6.2 Functional failures

Historically, there have been 45 functional failures[9] of structures since 1959. A functional failure of structure is an event which prevents the safe flow of electricity from one terminal station to another. The safe flow of electricity is partly achieved by ensuring adequate clearance is maintained between live apparatus and the ground or objects on the ground. This definition qualifies any failure which prevents the structure from providing the mechanical support required to meet ground clearance regulations while allowing electricity to be transported between terminal or power stations. A typical functional failure mode is structure collapse due to extreme weather conditions. Figure 14 and Table 4 illustrate the history of structure functional failures on the Victorian transmission network.

[8] It's only been 2 months into FY2020 during the time of writing of this AMS.

[9] This figure excludes cross arm failures resulted from installation errors and mechanical overloading of cross arm members during maintenance works. It also excludes transmission line structure footing failures.

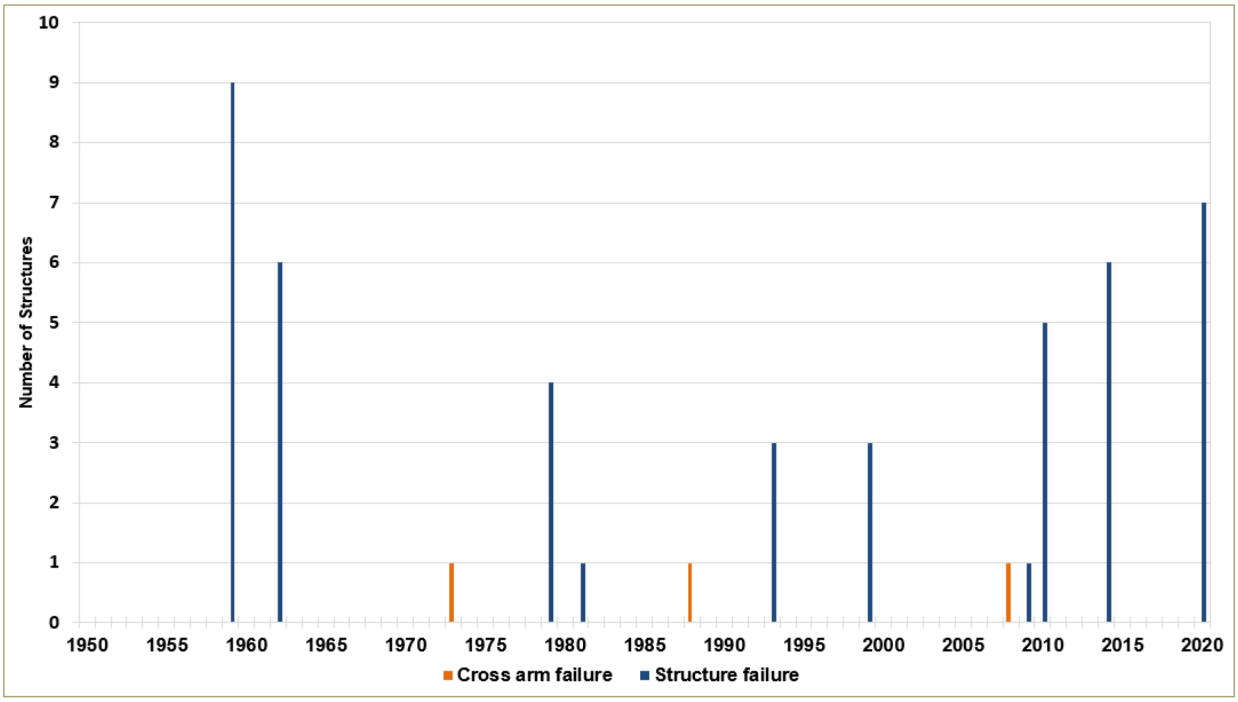

Figure 14 – Structure functional failure history

Eleven separate events have led to the collapse or failure of 45 structures in 61 years. In most cases the collapse of one structure caused several other structures to fail with the worst multiple-failure event taking place in 1959 on the Geelong - Colac 220 kV line when a total of eight structures failed. The Bendigo to Kerang 220 kV line has experienced four tower collapse incidents due to the tower design structural inadequacy for high intensity winds since it was constructed in 1961. A total of 18 towers have failed from four separate events in 1979, 1993, 2010 and 2014.

On the 31st of January 2020, at around 2:46pm, an extreme weather event called a severe convective downburst went across the transmission line near Cressy which is located a few kilometres from Geelong. The intensity of the wind was so strong that it brought down six-500kV towers and damaged a seventh tower. The six towers fell almost perfectly transverse to the line's alignment while the seventh tower was twisted along its superstructure. This tower fortunately did not collapse as it was only a few metres from an arterial road and the event occurred just as a road user was travelling underneath the circuits.

Table 4 – Structure collapse incidents

Year	Number of towers	Cause	Tower Type	Voltage	Location
1959	1	Extremely high winds	Suspension tower	220 kV	Yallourn-Melbourne
1959	8	Extremely high winds	Suspension towers	220 kV	Geelong-Colac
1962	6	Tornado	Suspension towers	220 kV	Geelong-Colac
1979	4	Severe Thunderstorm	Suspension towers	220 kV	Bendigo-Kerang
1981	1	Windstorm	Suspension tower	330 kV	Murray - Dederang No.2
1993	3	Severe Thunderstorm	Suspension towers	220 kV	Bendigo-Kerang
1999	3	High intensity wind gusts	Suspension towers	330 kV	Dederang- South Morang No.2
2009	1	North-westerly winds plus convection effect of bushfires	Suspension tower	330 kV	Dederang- South Morang No.1
2010	5	Microburst wind during severe Thunderstorm	Suspension towers	220 kV	Bendigo-Kerang
2014	6	Severe Thunderstorm	Suspension towers	220 kV	Bendigo-Kerang
2020	7	Downdraft wind during severe Thunderstorm	Suspension towers	500 kV	Moorabool-Heywood

The mean time between failures (MTBF) of transmission line structures has declined since 1992 due to failures of low strength towers in extreme winds. The initial improvement since 1959 was due to an increasing population size of higher strength structures, in acknowledgement of the inadequacies in early design standards. The improvement in the MTBF which was achieved since 2015, upon completion of the tower strengthening works along Bendigo to Kerang 220 kV line, the Dederang to South Morang No.1 and No.2 330 kV lines was impacted by the latest incident along the Moorabool to Heywood 500 kV line. With this latest event, the MTBF was downgraded to 6.4 years as shown in Figure 15.

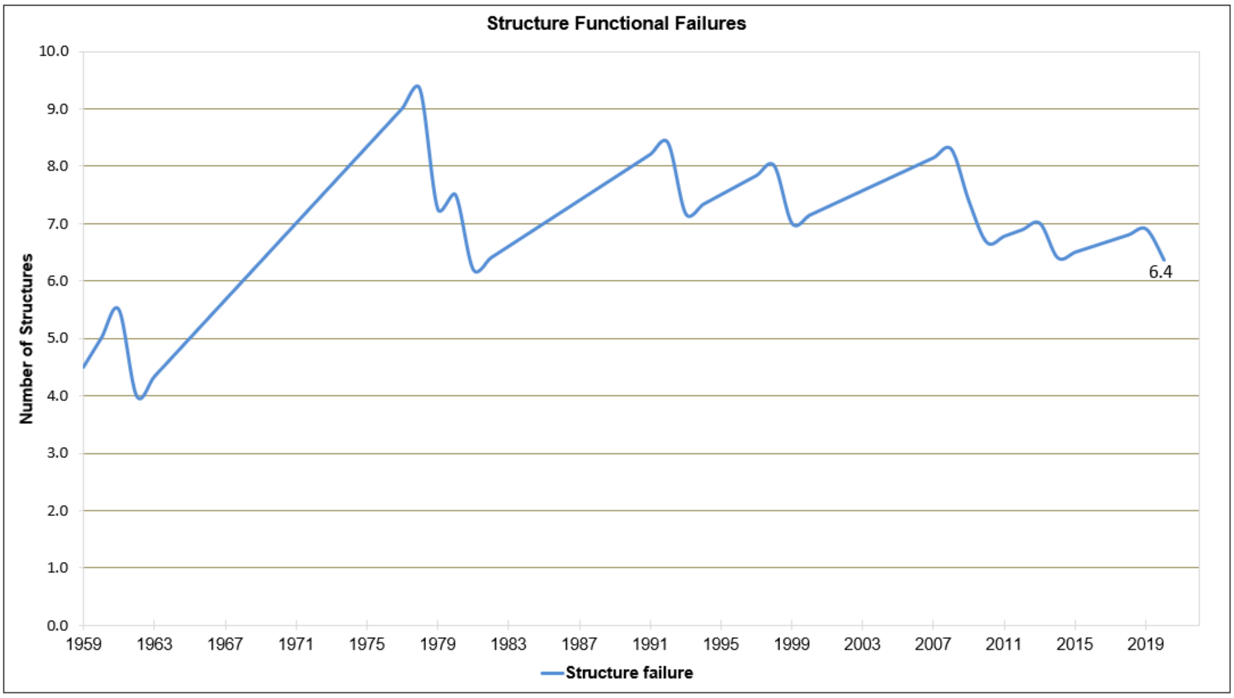

Figure 15 – Transmission Line Structures MTBF

3.6.3 Tower upgrade works

Victoria is a Zone III[10] wind load area which includes synoptic (gales) and convective (downburst, microburst) winds. Extreme winds have been the root cause of all structure collapse events triggering compression failures of supporting members on suspension structures. The Victorian transmission network extends across two wind regions[11] including A1 and A5. Region A5 comprises a 70-kilometre radius around Melbourne CBD and A1 covers the rest of the state. All structure collapse events have taken place in wind region A1. Figure 16 displays Australia's wind regions.

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

[11] AS/NZS 1170.2:2011 Structural Design Actions – Wind Actions. Standard AS/NZS 1170.2 details wind actions by classifying Australia into four different regions comprising A (divided into subregions A1 to A5), B, C and D and provides these regions with a wind speed value for each average recurrence interval. For the same return period, different spatial regions of the Australian continent have different regional wind speeds with basic wind speeds increasing in magnitude from region A to D.

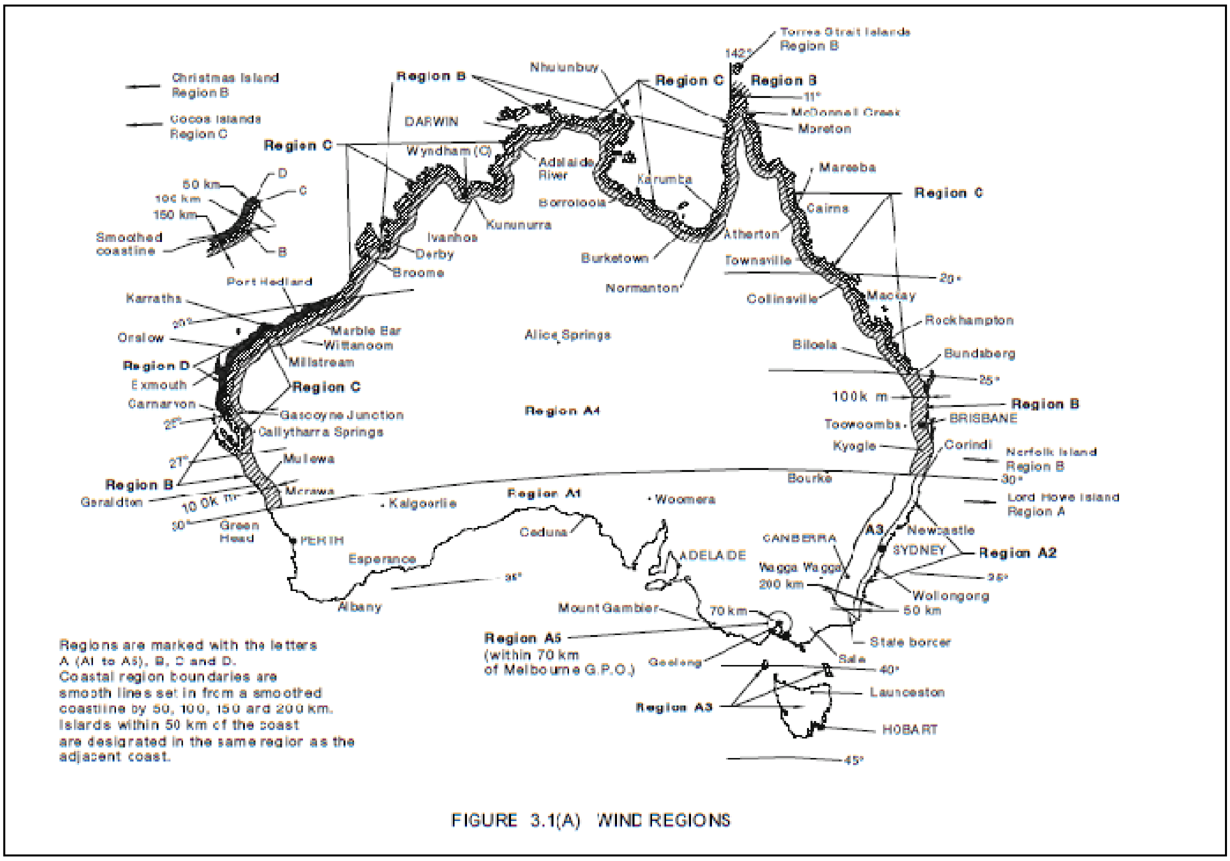

FIGURE 3.1(A) WIND REGIONS

Figure 16 – Wind Regions and Locations of Structural Functional Failures[12]

A program of strengthening works has resulted in the upgrade of multiple light suspension structures in areas of exposure to extreme wind conditions. Strengthening works first began in the 1970's and have been performed on structures situated on several lines including Dederang to Glenrowan 220 kV, Glenrowan to Shepparton 220 kV, Shepparton to Bendigo 220 kV, Keilor to Geelong 220 kV and Moorabool to Kerang 220 kV.

In 2013, eleven structures along the Bendigo to Kerang 220 kV line were replaced with new structures designed using the latest design standard AS/NZS 7000 to correct unacceptable failure risks over major roads. Three years after this project, TD-3525 (XC78) upgraded 74 towers along the Dederang to South Morang 330 kV No.1 and No.2 lines to mitigate the risks associated with road crossings as well as improve the reliability of the line.

Another project, TD-5956 is currently awaiting approval to upgrade 60 towers from the Murray Switching Station to Dederang Terminal Station (MSS-DDTS) Nos. 1 and 2 circuits 330 kV line. Similar with previous tower upgrading projects, its objective is to mitigate the risk of tower failure across major roads and improve the reliability of the line. This project has a completion date of 31st March 2022.

3.6.4 Corrosion Mitigation Program

The structure corrosion mitigation program is required to extend the life of targeted structures where replacements are not feasible due to high cost, limited easement availability, and prolonged outages. Typical corrosion mitigation works include partial or whole structure painting, and replacement of small volumes of crossarms or members which are excessively corroded.

Structure painting is a maintenance program that seeks to arrest the deterioration of the structure by introducing a barrier system to prevent moisture and/or airborne salts coming in contact with the steel members and bolts. Optimal timing of initial structure painting followed by patch work painting every ten or fifteen years will extend the service life of the structure beyond its original expected life.

Condition assessment surveys conducted at regular intervals assess the degree of corrosion steel members and bolts have experienced. A condition rating which corresponds with the level of deterioration is assigned as

[12] AS/NZS 1170.2:2011 Structural Design Actions – Wind Actions.

discussed in section 3.4. Structures with a condition grade between C3 and C4 are considered for structure painting to prevent further sectional loss which will ultimately lead to premature replacement of structures or functional failures of structure.

Structure painting simply preserves the existing structural strength of steel members and so the timing of painting activities is critical. Members that have experienced section loss consistent with grades C4 and C5 generally have experienced considerable reductions in material strength disqualifying them as suitable candidates for painting. These members and bolts must be replaced in conjunction with the tower painting works so the original strength of the tower is retained which assures its reliable performance.

Twenty-one structures along the Heywood Terminal Station to Alcoa Portland 500 kV Nos. 1 and 2 lines (HYTS-APD) have been identified for corrosion management including member and bolt replacement works. These structures, which were painted more than fifteen years ago have had its coating systems deteriorated to a point that section loss has occurred due to the severe corrosivity of the environment.

In addition to these structures, seventeen towers along the Rowville to Springvale 220 kV lines and the Springvale to Heatherton 220 kV lines are programmed for coating. Another seventeen 66 kV poles on Morwell to Loy Yang Power Station 66kV line are also showing signs of extreme corrosion and require painting program to extend their asset lives. Prior to painting the structures, the remaining sectional thickness of the poles should be assessed using an acoustic or electronic section measuring device to confirm the structural reliability and service life of the assets.

3.6.5 Fall Arrests Systems

AusNet Services has approximately 13,000 towers and more than 650 rack and ancillary structures such as ground wire masts and termination masts, which are climbed at regular intervals for inspection purposes. While the electricity industry has an excellent record with no recorded fall from a tower by a worker on duty, the general construction industry in Victoria has a very poor record. A fall from an elevated position on a tower could result in severe injuries or possible fatality to a worker.

The Occupational Health and Safety Regulations 2007, No. 54 – Part 3.3 prompted AusNet Services to initiate the installation of permanent fall arrest systems (FAS). In 2010, after a comprehensive study which compared several different types of FAS in the industry and several trial installations at the South Morang Training centre, the most effective FAS was deemed to be a cable FAS from the manufacturer [C-I-C], branded the [C-I-C] system.

Upon completion of two fall arrest installation programs, 82% of the tower fleet has been installed with a permanent Fall Arrest System. Stage 3 of the program has been scheduled to commence during FY2022/23 albeit in a slower pace. For this stage, the installation work of the FAS is going to be included in the scope of any project, CAPEX or maintenance, that will require tower access.

AusNet Services has completed the installation of a permanent FAS in half of the terminal and power stations it owns and operates. The work completed represents 62% of line rack structures and groundwire masts population. The completion of the installation on the rack and groundwire mast fleet is expected to be done during FY 2022/23 to TY2027/28.

4 Other Issues

The key issues associated with the transmission line structure fleet are as follows:

- Structure members can be damaged following impact from vehicles and farming machinery or can be removed by unauthorised third parties.
- As required by the current tower code, AS/NZS 7000:2016- *Overhead line design*, if a structure undergoing modification is deemed to be overloaded by structural analysis using its original design code, it must be upgraded to latest standard, including all reference standards.
- The Australian standard for wind loading, AS/NZS 1170.2: *Structural design actions, Part 2: Wind actions*, is under review as of the writing of this document. This is an acknowledgement by the engineering community in Australia, as headed by the Institution of Engineers of Australia via Standards Australia that the wind events in the country has changed over the past two decades.

5 Risk Assessment

To manage transmission line structures in a prudent and economic way, AusNet Services has undertaken fleet wide risk assessments using semi-quantitative analysis. Structure failure risk assessments support asset management planning and ensure that risks associated with transmission line structures are managed appropriately.

5.1 Overview

The Risk Matrix or Consequence/ Likelihood methodology is a semi-quantitative analysis using numerical, ordinal or interval scales to rate the consequence and/or likelihood of an event occurring. This type of risk analysis is used to assess overall network risks and specific high-level risks, such as bushfire ignition, health and safety, market impact/value of unserved energy, and collateral damage.

This process brings together asset condition data, asset failure rates, the design standard used for the structure, and the cost impact of asset failure to determine an economically justifiable level of replacement. This section summarises the reliability modelling of structure fleet.

Key inputs to this process are as follows:

- asset condition,
- remaining service potential (RSP %),
- failure rate and
- failure effects[13] .

Structures situated in the "severe" corrosivity zones have considerably shorter lifecycles when compared to assets in the "moderate" and "low" corrosivity zones.

AMS 01-09 *Asset Risk Assessment Overview* provides more detail in the Consequence/Likelihood Matrix.

5.2 Risk Assessment Methodology

The risk matrix methodology is a semi-quantitative process wherein the tower fleet is presented in a 5 x 5 matrix using condition and criticality as its axes.

The methodology is used to identify the population of towers which is economic to replace during next regulatory period. The volume only includes assets which are owned by the Regulated Business, as discussed in section 2.2.

- Life Expectancy is based on actual and suspended failures, as well as calculating a structure's service life based from corrosion rates[14].
- Characteristic age, Eta (η) and Failure Shape Factor, Beta (β) were derived using the Weibull module of the software program, Availability Workbench
  - - Structures that have failed (collapsed) are attributed to high intensity wind events which are random in nature.
  - - Steel members that were replaced are represented in the analysis by entering its age (in hours) during the time of replacement. These assets are identified as being "suspended failures"
  - - The program is made to execute its analysis and the Beta and Eta values are provided
- Weibull parameter calibration is achieved by:

[13] Effect costs were calculated against each of the possible failure effects discussed in section 3.5 including bushfire ignition, health and safety, value of unserved energy and collateral damage. The total failure effect cost for each asset was taken as the sum of all failure effects

[14] A project was undertaken in 2015 which span for 3 years wherein steel coupons were installed on towers at various areas in the transmission network and exposed to the environment. Every year coupons were collected and weighed to determine the rate of section loss due to corrosion. At the end of the project, the annual corrosion rate was calculated, and three Corrosivity Zones were established.

- Calibrate Eta and Beta to arrive at similar number of failures[15] as experienced in practice.
- All calculations were made using the actual structure population for each condition score bracket and separately for each corrosivity area.
    - The Criticality Score is assigned to each structure by adding all the consequences of a structural failure, dividing the value by the replacement cost of the structure, and then grouping this into criticality bands as per Table 3 in Section 3.5.

5.2.1 Structure Risk Matrix

Table 5 below shows there are 23 structures that belong to Risk Category A which are in C4 Condition (i.e. structures still have 25% remaining life). These structures are assessed during condition assessment which is done on a regular basis and the action required is to delay the rate of degradation of the structures by applying coating systems and extend the structure's service life.

Out of the 23-structures, four towers will need to be replaced to assure the circuits' reliability and safety of the public during the period FY2022/23 to FY2027/28. Detailed analysis has indicated that replacement rather than re-coating is more feasible due to the number of members and bolts that have been affected by corrosion.

Table 5 – Structure risk matrix

	CONDITION					
Criticality	C1	C2	C3	C4	C5	Grand Total
5	227	541	21	0	0	789
4	781	2371	295	23	0	3470
3	513	2666	789	14	0	3982
2	1013	2817	233	6	0	4069
1	39	55	6	0	0	100
Grand Total	2573	8450	1344	43	0	12410

5.3 Program of Works

The proposed program of works for the structure fleet in the next regulatory period involve the replacement of four highly corroded structures along the HYTS-APD 1 and 2 500 kV circuits, the installation of fall arrest systems on towers which will have replacement programs implemented on them such as insulators, conductors and groundwires, and the corrosion mitigation works on affected towers.

5.3.1 Tower replacement

It is envisaged that towers T619, T624, T625 and T626 will be replaced rather than painted to assure the circuits' reliability and safety of the public. Detailed analysis has indicated that replacement rather than re-coating is more economical, feasible and safe, given the number of members and bolts which have suffered serious corrosion on the structures.

5.3.2 Structure fall arrest system

Upon the start of the regulatory period, 82% of transmission structures and 62% of rack structures inside terminal stations will have permanent fall arrest system installed on them. This program will address one of the business' critical risks associated with a fall from height.

Following the Risk Management philosophy of minimising risk exposure of AST personnel to "As Low As is Reasonably Practicable," structures which are included in the coming Regulatory Period for some CAPEX

[15] Failures represent actual and suspended failures.

Programs and Maintenance, e.g. insulator/conductor/groundwire replacement; and are scheduled to be climbed for condition assessment, have been included in the FAS Installation Program

The list of structures included in the two programs, Structure FAS and Rack Structure FAS is attached in Appendix C: Tower Fall Arrest Program.

5.3.3 Corrosion Mitigation works

The list of towers along HYTS-APD 500 kV line, ROTS-SVTS 220 kV line and poles along MWTS-LY 66 kV lines are provided in Appendix D: Corrosion Mitigation Works Program.

6 Strategies

High level strategies to be adopted for prudent and efficient management of the transmission structure fleet are:

6.1 New Assets

- New structures are designed and constructed in accordance with current industry guidelines and standards[16].

6.2 Inspection

- Continue to assess the condition of transmission line structures during structure detail inspections which are conducted at 3, 6 or 9 yearly intervals.
- Continue to use of Field Mobile Inspection (FMI) technologies for the collation of condition assessment data which facilitate automatic updates of Asset Management databases.
- Explore and introduce new technologies in performing structure inspections to improve the effectiveness, productivity, and safety of workers.[17]

6.3 Maintenance

- Continue to replace corroded or damaged steel members and bolts as part of corrective and scheduled maintenance programs.
- Continue to perform corrosion mitigation works on corroded structures, specifically on towers along HYTS-APD 500 kV, ROTS-SVTS 220 kV, SVTS-HTS 220kV, and poles along MWTS-LY 66 kV circuits.
- Perform fleet wide risk assessment to identify corrosion mitigation works based on the structural strength, corrosivity zone and failure effects.
- Use the emergency restoration structures (ERS) to temporarily reinstate a line impacted by high intensity winds.

6.4 Spares

- Continue to maintain sufficient strategic spares Transmission Line structures and associated hardware.

6.5 Refurbishment

- Continue to install Fall Arrest Systems (FAS) on remaining Transmission Line structures by including the installation into the scope of projects.
- Complete the installation of FAS on all rack structures and ground wire masts in Terminal stations by 2027.
- Perform structural modelling of existing structures as part of tower upgrades and other lines projects, e.g. conductor and ground wire replacement projects.

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

[17] AMS 10-75: Transmission Line Insulators mentions the use of RPAS (Drones) with thermal scanning capability to inspect polymeric insulators together with condition assessment inspections.

Appendix A – Corrosivity Zones on the Victorian Transmission Network

[C-I-C]

Appendix B – Bushfire Consequences on the Victorian Transmission Network

[C-I-C]

Appendix C Fall Arrest Installation Program

Row Labels	Insulator Replacement POW	GW Replacement POW	GW Replacement & Ins Replacement POW	Conductor Replacement POW	Cond Replacement & Ins Replacement POW	Grand Total
HWTS-ROTS 3	1	3		2		6
HWTS-ROTS 3R	4	4	1			9
HWTS-SMTS 1	7					7
HWTS-SMTS 2	1			6	1	8
MSS -DDTS 1	1	5		6		12
MSS -DDTS 2		2				2
SYTS-MLTS 1		3				3
SYTS-MLTS 2		1		6		7
Grand Total	**14**	**18**	**1**	**20**	**1**	**54**

Appendix D Structure Painting Program

Circuit Names	Voltage	C2	C3	C4	Grand Total
HYTS-APD 1	500 kV		17	6	23
HYTS-APD 2	500 kV			1	1
MWTS-LY 1	66 kV		13		13
MWTS-LY 2	66 kV		4		4
ROTS-SVTS 1	220 kV	5	1		5
SVTS-HTS 1	220 kV	10	1		11
Grand Total		15	36	7	58