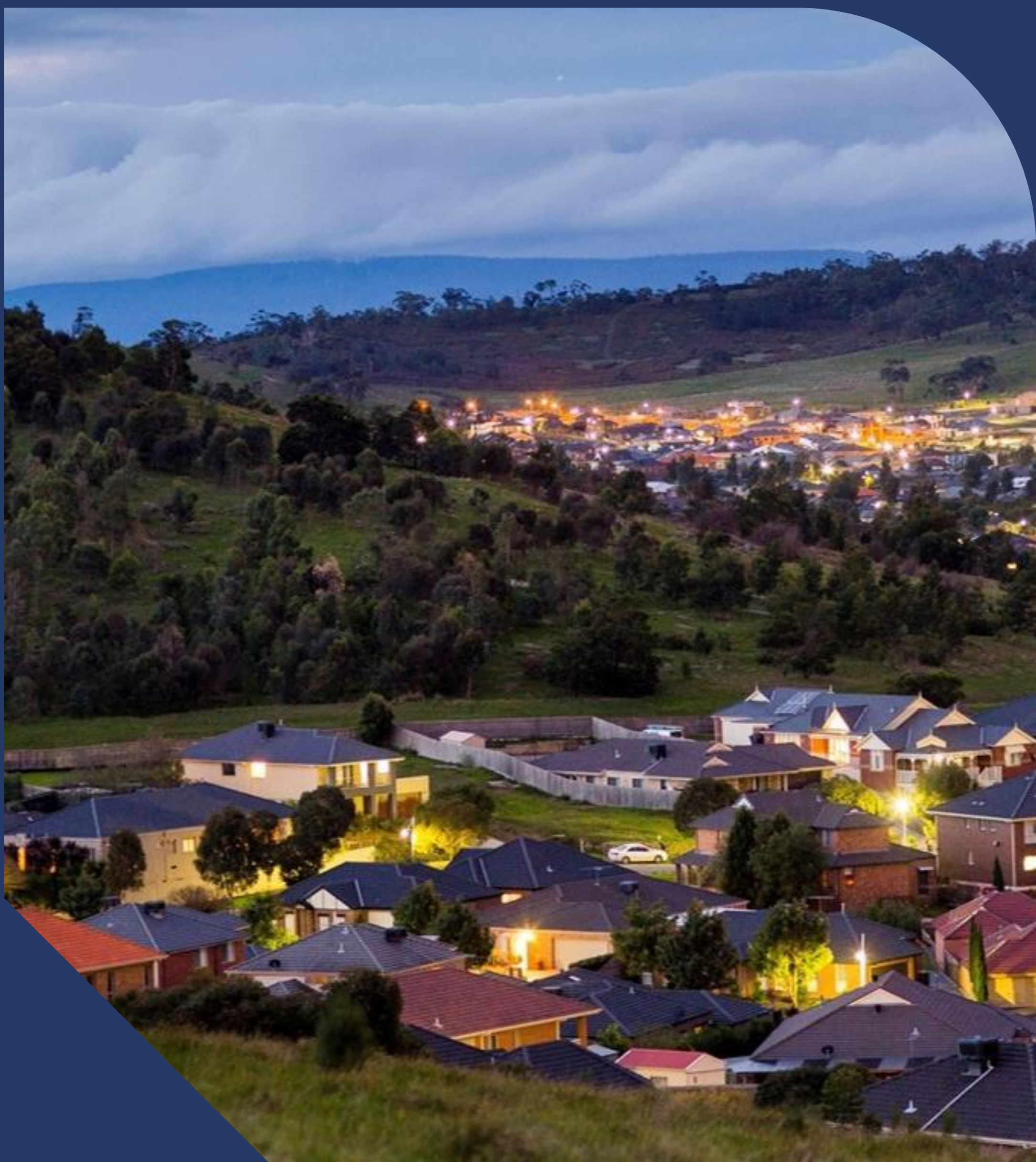
Transmission Line Insulators

Asset Management Strategy



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Abbreviations and Definitions

TERM	DEFINITION
AER	Australian Energy Regulator
CoF	Consequence of Failure
EDPM	Ethylene Propylene Diene Monomer
FMECA	Failure Mode, Effect and Criticality Analysis
FMI	Field Mobile Inspection
MIC	Market Impact Component (of STPIS)
PoF	Probability of Failure
RCM	Reliability Centred Maintenance
RPAS	Remotely Piloted Aerial Systems
SAIP	Smart Aerial Inspection and Processing
SAP	Systems, Application and Processing – AusNet's asset management system
SC	Service Component (of STPIS)
STPIS	Service Target Performance Incentive Scheme
TNSP	Transmission Network Service Provider
TRR	Transmission Revenue Reset

1. Executive Summary

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

Insulators provide a mechanical connection between live conductors and structures whilst insulating the structures from electrical current. Approximately 89,000 insulator strings (17,996 insulator equipment locations) are in service on the transmission network. Most insulator strings are comprised of several linked discs made from either porcelain or glass with steel pins to form a continuous string. There are a growing number of polymeric insulators in operation.

AusNet has undertaken several programs of targeted insulator replacements. Since 2006 there have been 5 programs replacing aging or defective Porcelain & Glass Insulators with Polymeric Insulators. From 2006 to 2025 approximately 40% of Insulators on the Transmission network have been replaced. The ongoing condition assessment program, and learnings from major failure root cause investigations and forensic sampling, form the foundation for these past and future programs.

A risk-based assessment has been undertaken, focusing on the condition and likelihood of failure and the consequences of failure including safety, community impact, environmental, and market impact considerations. A total of 1551 insulator equipment locations (9.0% of the insulator fleet) are forecast for replacement. 80% of these replacements are on the 500kV lines. This is due to the deteriorated condition, and the high failure consequence locations.[1]

The overall strategy emphasises proactive management through scheduled preventative inspections and maintenance, non-invasive condition monitoring, and prioritised replacement program.

1.1. Asset Strategy Summary

AusNet's strategy focuses on proactively managing risk, ensuring safety, and maintaining reliability through a targeted program of replacement, refurbishment, and maintenance actions across the asset lifecycle stages. For new assets, polymeric insulators are the standard choice due to their performance benefits, though precautions are taken to prevent bird damage during installation[2]. Disc insulators are still used primarily on strain towers, as bridging strings to utilise their weight on the bridging conductors.

Our inspection strategy prioritises regular condition assessments through climbing inspections and annual line patrols. Increasingly, we are integrating advanced technologies and post maintenance data capture processes to enhance coverage and data quality. These include, Remotely Piloted Aerial Systems (RPAS) for aerial inspections, Smart Aerial Inspection and Processing (SAIP) for automated defect detection and analysis, Digital data capture via field mobile systems, and photographic and video evidence records for condition tracking and historical reference. This approach supports proactive asset management and improves decision making through better visibility of asset condition over time.

This comprehensive, risk based asset strategy aims to satisfy stakeholder expectations for safety, reliability, cost effectiveness, and environmental responsibility.

[1] There is an approved project (TD-4197 to replace 1,940 strings) on various transmission lines over two financial years from 2019/20 to 2020/21.
[2]Polymeric insulators are particularly vulnerable to bird attacks when strung under de-energised conditions where the rubber sheds can be chewed.

2. Introduction

2.1. Purpose

This document defines the asset management strategies for insulators on lines forming AusNet's regulated electricity transmission network. This includes the inspection, condition assessment, maintenance and replacement activities required for the life cycle management of these assets.

This document is intended to be used to inform asset management decisions and communicate the basis for these activities.

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

2.2. Scope

This asset management strategy applies to all transmission line insulators, as well as all associated hardware and fittings, within AusNet's regulated electricity transmission network that operate at voltages of 66 kV up to 500 kV in the state of Victoria.

This asset management strategy does not cover:

- Insulators operating on Ausnet's distribution network.
- Insulators and hardware owned by AusNet's unregulated contestable business.

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

2.3. Asset Management Objectives

As stated in REF: AMS 01-05 Strategic Asset Management Plan, asset management objectives and Strategic pillars are:

Trusted to bring the energy today and build a cleaner tomorrow							
Strategic Pillars						Ambition	
Safely deliver our customer's energy needs today				Create the energy network of tomorrow	Enable the transition to a net zero future	Be a leader in asset management practice	
Asset Management Objectives						Enabling AMOs	
Safety: Minimise risk to our people, contractors, customers and communities AFAP across our networks	**Reliability:** Meet the reliability expectations of our customers and communities, and meet our reliability targets	**Resilience:** Improve the resilience of our network to adapt to a changing climate and energy system environment	**Compliance:** Comply with all legislation, regulations, relevant standards and industry codes	**Planning and decision-making:** Deliver valued planning and network outcomes through optimising asset lifecycle management	**Sustainability:** Build stakeholder trust and deliver social value. Reduce our environmental impact. Operate efficiently to sustain financial value creation.	**Competency and capability:** Develop asset management capability and competency in the organisation	**Continuous improvement:** Continually improve asset management maturity for effective delivery of services

3. Asset Description

3.1. Function

The insulator assembly provides the dual function of a mechanical connector and an electrical isolator between the current carrying phase conductors and the earth connected support structure, which can either be a steel lattice tower or utility pole made of concrete or steel.

The insulator assembly consists of the insulator string and its associated hardware and fittings. An insulator string can be made from several discs connected in series, or a single unit made from polymeric materials.

Insulator hardware includes the corona ring aka grading ring, which is used to minimise the discharge of corona from the live conductor, and the suspension clamp, which is used as a cradle to support the conductor in a suspension structure[3].

Insulator fittings include the shackles, extension links and clamps which are used to adjust the distance of the conductor from the structure. Termination joints, which are used in strain structures[4], are considered part of the conductor system and are excluded from the insulator assemblies.

3.2. Population

There are approximately 89,000 transmission line insulator strings in service (at 17,996 insulator equipment locations) on the regulated transmission network, as of 1 August 2025. The majority of insulator strings are comprised of linked discs made from either porcelain or glass with steel pins to form a continuous string. The number of discs on a string increases with the operating voltage of the line as well as creepage length required for adequate pollution performance[5]. The numbers of porcelain or glass discs required for different voltages are shown in Table 1.

VOLTAGE (KV)	NUMBER OF PORCELAIN/GLASS DISCS
66	8
220	13 – 17
275	19
330	18 – 20
500	23 – 35

Table 1: Number of porcelain/glass discs per insulator string by voltage

A polymeric string consists of composite polymer material that has a fibreglass core with a sheath made from silicone rubber or ethylene propylene diene monomer (EPDM). Unlike porcelain or glass strings which contain individual insulators joined together in series; polymeric strings contain a single continuous fibreglass core. The number of polymeric sheath rings surrounding the fibreglass core increase along with increasing operating voltage, however these rings vary in size and distance from one another and number depending on the insulator manufacturer.

The population of transmission line insulators include three different types which are identified by materials used in their manufacture, namely porcelain, glass and polymeric. Each different type of insulator displays different

[3] Suspension structure - a structure wherein the conductor passes as one continuous unit, without any (or minimal) line deviation.
[4] Strain structure – a structure used when there is a deviation in direction of the line. The conductor is terminated at one side of the tower and connected to the conductor on the adjacent side, using a bridging conductor supported by an insulator bridge assembly.
[5] More discs are required for polluted or aggressive environment such as the vicinity of power stations, near the coastline or within the metropolitan area.

performance characteristics in terms of corrosion and pollution resistance, tensile strength, and electrical insulation properties.

The population of transmission line insulators operate at five nominal system voltages, 500 kV, 330 kV, 275 kV, 220 kV and 66 kV.

Figure 1 displays photographs of the different insulator types in service on the transmission network.

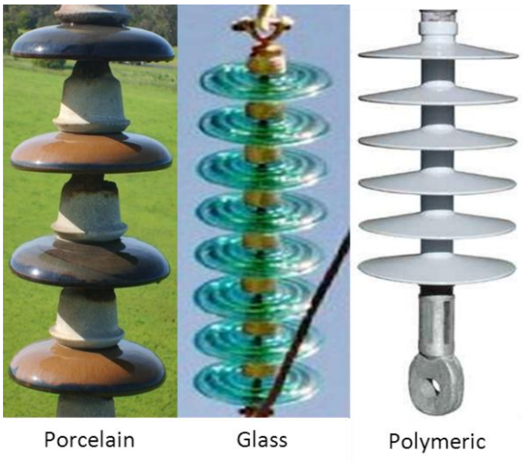


Figure 1: Insulator types

Table 2 summarises the volumes of different types of insulators operating within each of the five voltages.

INSULATOR TYPE	66 KV	220 KV	275 KV	330 KV	500 KV	TOTAL
Porcelain	2070	10400	1160	6600	23500	43730
Polymeric	0	14500	0	150	1800	16450
Glass	450	3450	15	2500	0	3965
Mixed	0	18500	120	2500	4000	25120
Total	**2520**	**46850**	**1295**	**9300**	**29300**	**89125**

Table 2: Transmission line insulator strings by voltage and type

Since 2006, deteriorated porcelain and glass insulator strings have been proactively replaced with polymeric insulators. Figure 2 is a graphical representation of the transmission line insulator fleet by type and voltage cohorts.

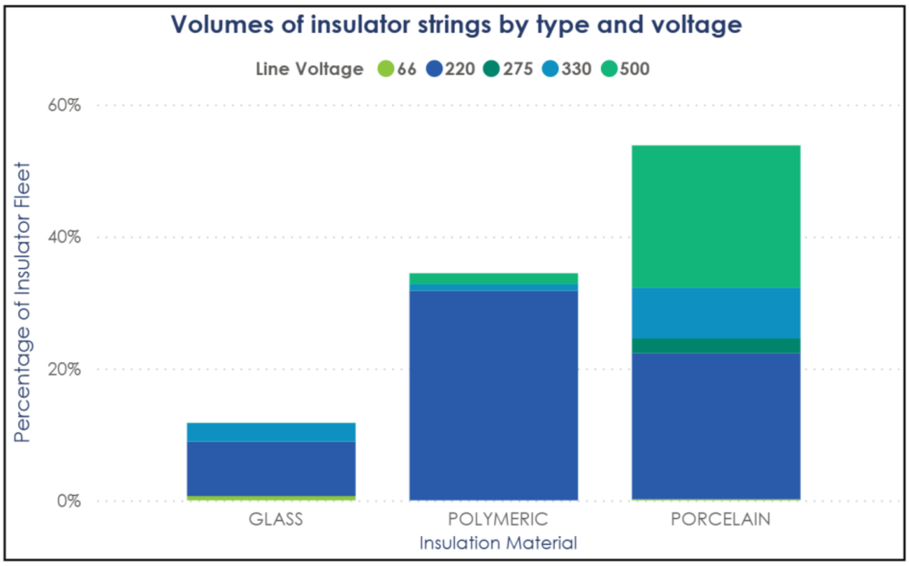


Figure 2: Volumes of insulator strings by type and voltage

3.3. Age

The average in-service age[6] of the transmission line insulator strings is 38 years as shown in table 3. This average has been influenced by the progressive replacement of deteriorated insulator strings. The table below shows the average age of insulator assets within the network.

VOLTAGE CLASS (KV)	AVERAGE AGE
500	43
330	56
275	37
220	35
66	44
All strings	**38**

Table 3: Average age of transmission line insulators

Figure 3 below shows the age of the transmission line insulator population by voltage. There are approximately 4613 insulator equipment locations with a service age exceeding 55 years; the majority of these insulators operate on the 220 kV network (predominantly corrosivity zone 1), followed by the 500kV (corrosivity zone 1 and 2).

[6] Note that AusNet Services' asset age data for insulators is based on the asset installation date, not the manufactured date.

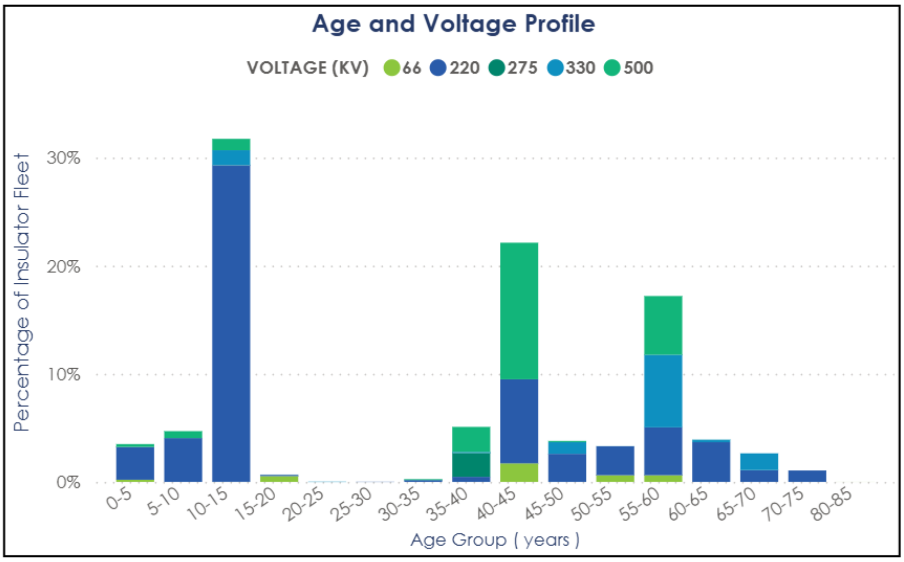


Figure 3: Transmission line insulators age bracket by voltage

Figure 3 also shows the significant condition risk based 220kV replacements over the last 15 years. The original 500kV insulator fleet in the highest corrosivity zone 3 have also been replaced.

Figure 4 shows the age of the transmission line insulator population by type, with the oldest transmission line insulators being either porcelain or glass type.

The majority of insulator strings with an age of 15 years or less are polymeric types, with new porcelain disc strings used only as bridging insulators on strain towers due to its weight, i.e. to keep bridging conductors from swinging too close to the structure during high winds.

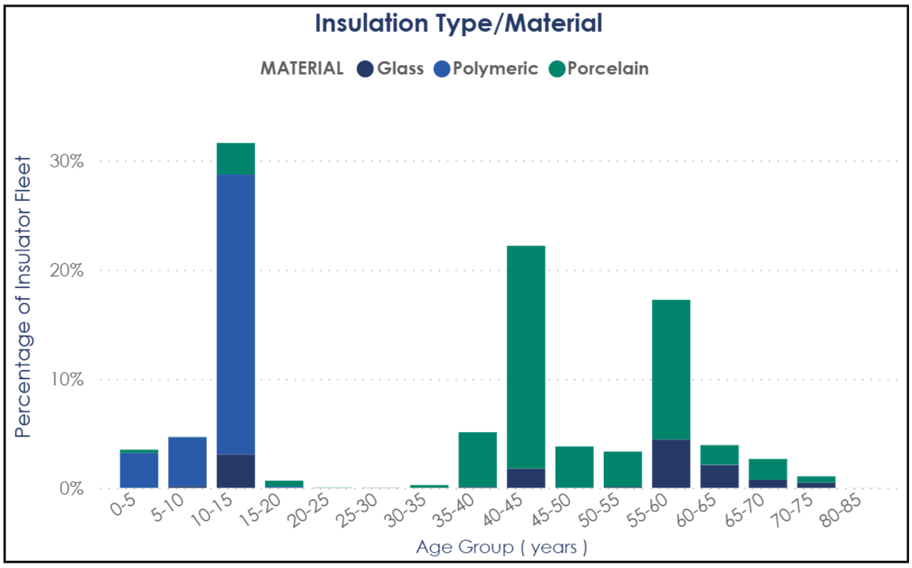


Figure 4: Insulator service age by type

4. Asset Performance

Inspections and condition assessments are a critical element of lifecycle management for Transmission line Insulators. These assessments provide vital information on the current assessment of corrosion and effect of pollution enabling informed decision making regarding maintenance and replacement. Understanding how assets perform over time allows for proactive management, reducing the risk of unexpected failures. The assessment employed by AusNet involves analysing failure trends and any significant impacts resulting from failure, which provides valuable insights into the condition and reliability of the assets.

4.1. Suspended Failures

Suspended failures are defects or issues that are detected and rectified as part of corrective maintenance or replacement tasks before they cause a functional (or physical) failure such as an outage and/or conductor drop.

AusNet has adopted strict transmission line and easement inspection policies aimed at objectively assessing asset condition with a particular focus on assets which are not fit to remain in service.

Transmission line insulators deemed not fit for service are replaced by raising ZA Notifications (i.e. condition based work) in [C.I.C], AusNet's Asset Management System. Line insulators replaced via ZA Notifications do not result in a transmission line functional failure and are therefore classified as suspended failures.

Defect categories include Defective, broken, damaged and worn can occur across all three types of insulators and their hardware. Pollution on the insulator string is caused by local environmental factors such as salt deposition from coastal areas, dust in dry open areas or soot emitted from bushfires. Some high polluted lines are washed regularly, whereas most lines are washed upon assessment. A ZA notification is raised when washing is assessed as required,

Figure 5 shows annual counts of defective insulators from 2015 to 2025, grouped into six types: Broken, Corrosion, Damaged, Defective, Pollution, and Worn. Colour coded bars represent each failure type per year.

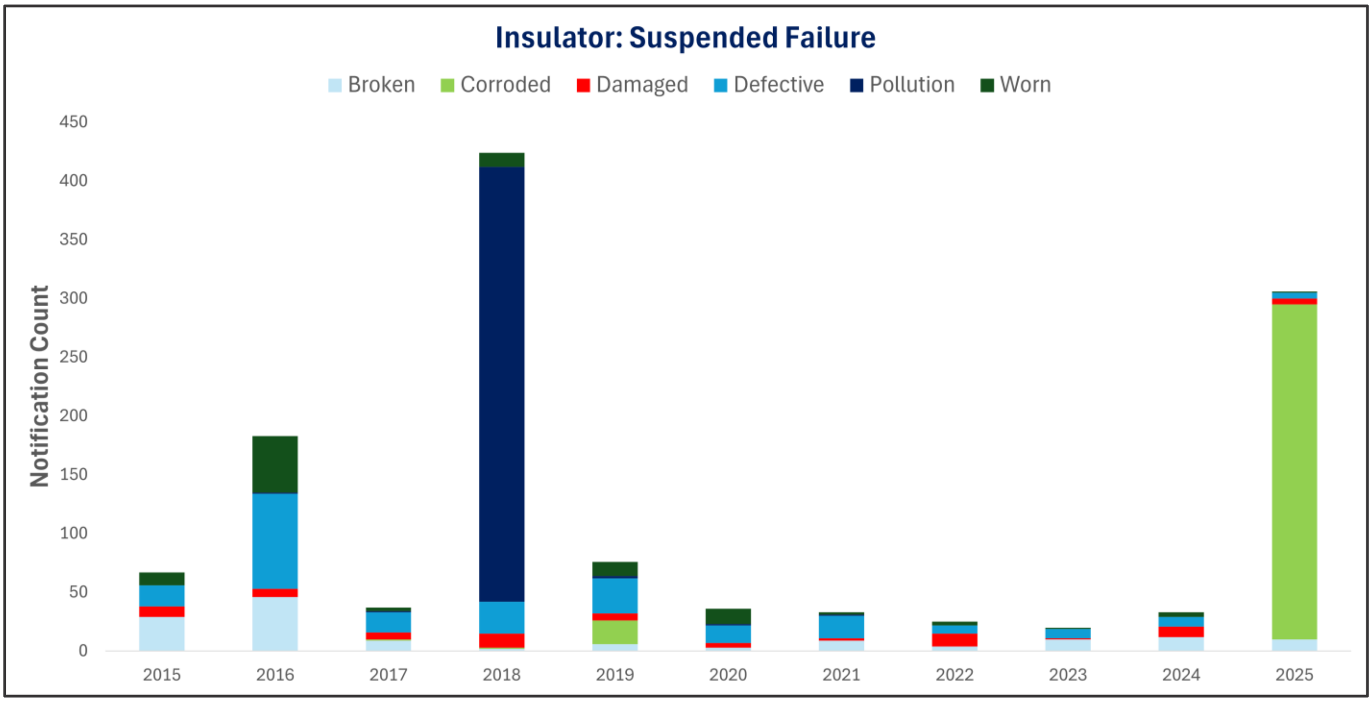


Figure 5: History of suspended insulator failures

In the last ten years, failures from broken, damaged, defective, and worn insulators have declined. Pollution and corrosion remain the main causes for corrective action.

In 2018, there was an increase in insulator washing notifications for the southwest lines due to soot deposits following the March bushfires in that region.

Most recently in 2025, corrosion notifications have dramatically increased where they now represent the most prominent defect type. This escalation is due to the insulators in the southwest being reinspected as part of their condition assessment cycle.

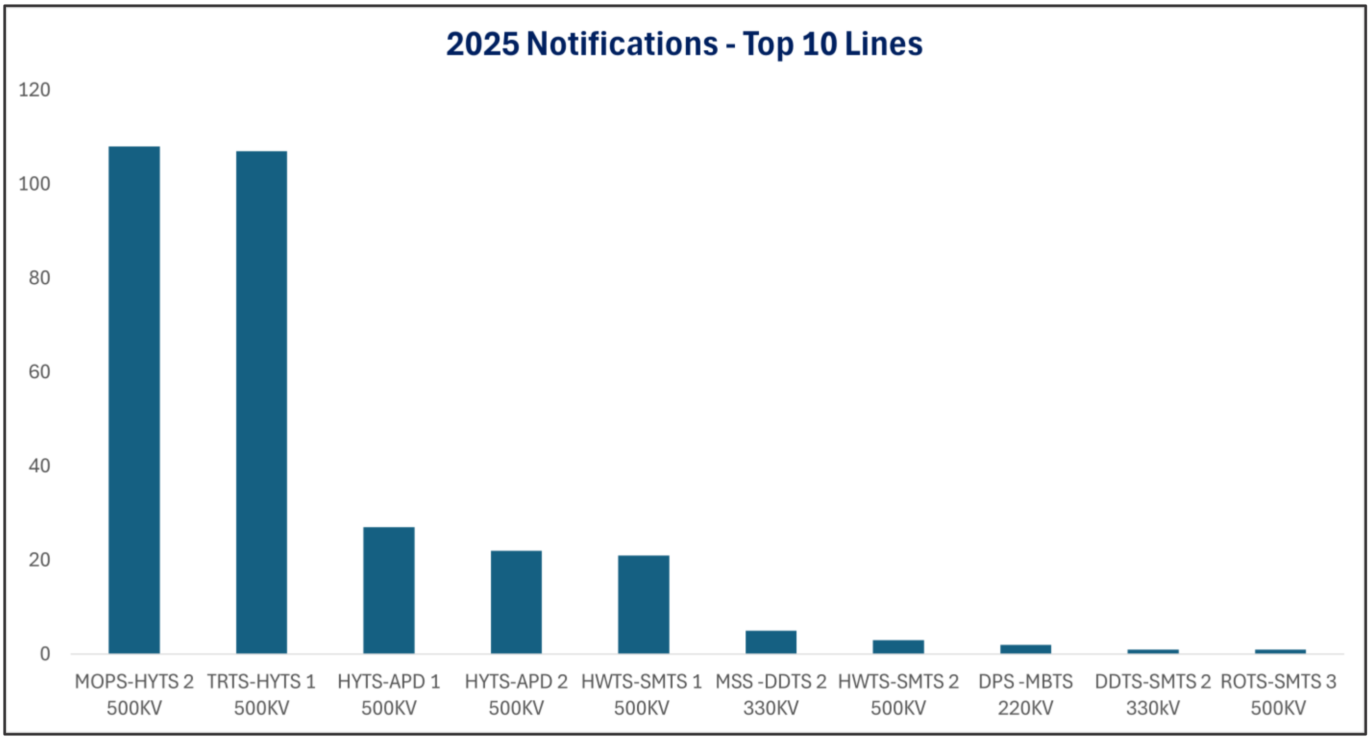


Figure 6: Drill down on 2025 Notifications

Figure 6 presents a drill down analysis of 2025 notifications, highlighting that the majority of reported issues by field personnel are corrosion related and concentrated within the southwest corridor, specifically between TRTS/MOPS and HYTS, extending through to [C.I.C]. Insulators and associated hardware in these segments account for the bulk of corrosion observations, consistent with their classification of C5 as determined through condition assessments. The predominant defect currently reported is the corrosion and fretting wear observed on the insulator hardware Y clevis pin arrangement.

A number of these insulators and their hardware are already scheduled for replacement in 2025-26 under in flight capital projects. Concurrently, forensic investigations are planned on removed insulator and clevis pin hardware samples to further substantiate the urgency of the assessments. The remainder of these insulators and hardware, not in the scheduled 25/26 program, are proposed as part of the 2027-32 insulator replacement program.

The assets identified with the notification status are subject to enhanced inspection protocols, with ongoing monitoring continuing until their scheduled replacement. Should any asset exhibit accelerated deterioration, it will be prioritised for immediate corrective replacement outside of the planned schedule.

The increase observed in 2025 highlights the need for a focus on timely asset condition monitoring, along with planned intervention strategies, particularly when a large cohort of assets are deteriorating at a similar rate across the network.

4.2. Functional Failures

A functional failure is a physical failure of an insulator string assembly resulting in either an outage or conductor drop.

Functional failures can be grouped into the following categories:

- Electrical
- Mechanical
- Aggressive environments
- Manufacturing defect
- Vandalism
- Work Practice

Electrical failure of porcelain or glass insulator can be caused by cracking which creates a path for current to flow through the insulator body or by pollution deposits allowing current to track across the surface of the insulator.

The mechanical failure mechanism for porcelain or glass insulators is physical separation caused by insulator pin corrosion, fitting wear or metal fatigue of the insulator pin and cap.

Electrical failure of polymeric insulators may be due to aggressive environments that can degrade the rubber sheath of a polymeric insulator which causes surface tracking or pinholes that allows moisture to enter the core of the string, causing internal arcing or excessive leakage currents to occur in the fibre glass rod until it suffers brittle failure.

Mechanical failure mechanism of polymer insulator may be due to bird damage or bullet damage.

Manufacturing defects may leave an unwanted gap between the core and sheath material or introduce a crack on the rod during crimping of the end seals which may allow moisture to reach the core which allows arcing to degrade the fibre glass rod until it fails.

Figure 7 shows the four insulator failures from 2015 to 2025, with their respected failure modes: Mechanical and Manufacturer defect. While there have only been four insulators failure in the last decade, their consequence of failure was significant, resulting in market impacts and safety impacts through the possibility of bushfire ignition or public safety risk.

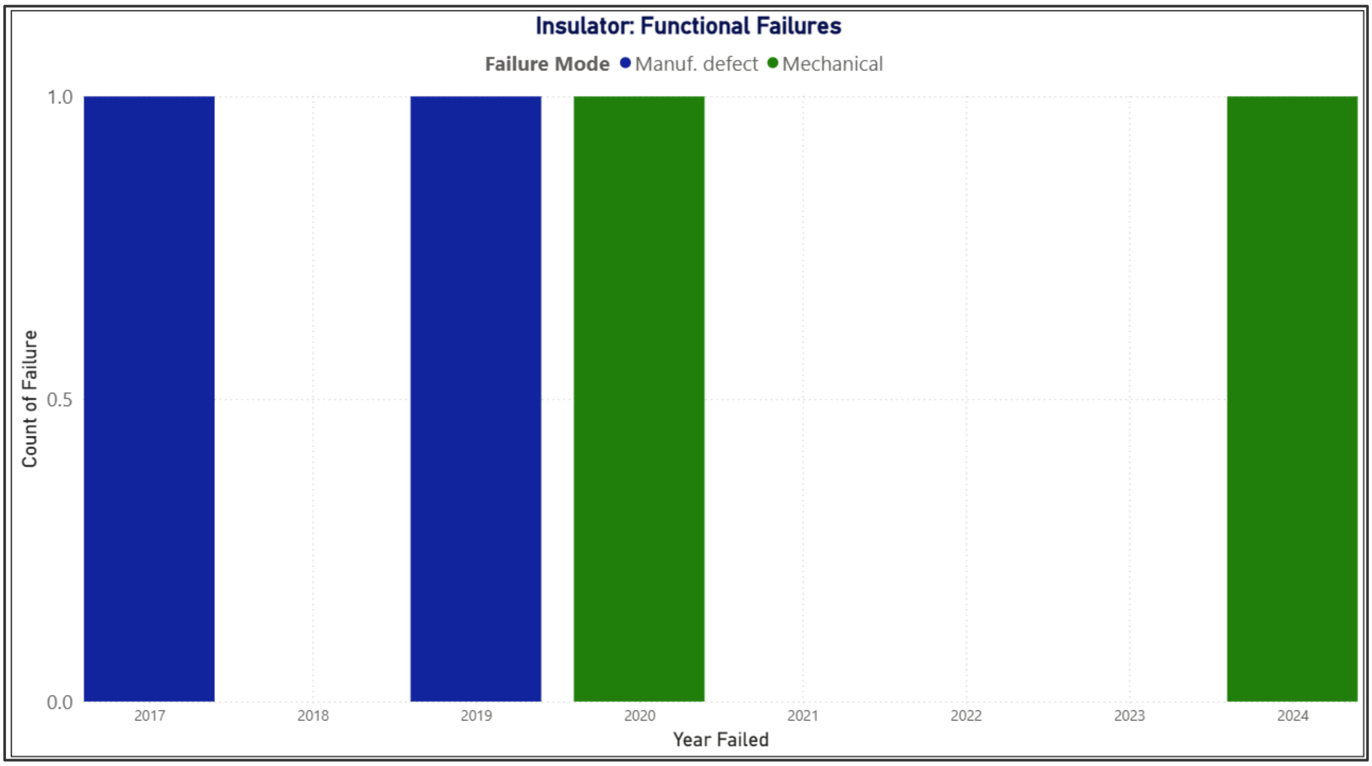


Figure 7: Insulator functional failures from 2017 to 2025

The failure that occurred in [C.I.C] will be addressed in detail in Section 4.3.1

Table 4 provides more details of 18 incidents of insulator functional failure over a longer period of 33-years.

LINE NAME	FAILURE MODE	FAILURE MECHANISM	INSULATOR TYPE	YEAR FAILED	AGE AT FAILURE (YRS.)
YPS-ROTS 5 220 kV	Mechanical	Pin fatigue	Glass	1993	37
BATS-BETS 220 kV	Mechanical	Pin fatigue	Glass	1999	37
KTS-WMTS 1 220kV	Manuf. defect	Defective shackle	Porcelain	2001	37
KTS-GTS 1 220KV	Mechanical	Pin fatigue	Glass	2003	39
KTS-WMTS 2 220kV	Electrical	Puncture	Porcelain	2003	39
MBTS-EPS 1 220kV	Mechanical	Hook fatigue	Glass	2004	44
MLTS-TGTS 220kV	Manuf. defect	Fatigue	Glass	2004	47
HWPS-ROTS 1 220kV	Mechanical	Pin fatigue	Glass	2005	39
YPS-ROTS 7 220 kV	Manuf. defect	Defective LL link	Glass	2005	49
ROTS-SVTS 2 220kV	Electrical	Puncture	Porcelain	2007	43
KTS-BLTS 220kV	Electrical	Puncture	Porcelain	2007	38
HWPS-ROTS 1 220kV	Mechanical	Pin fatigue	Glass	2008	42
BATS-BETS 220 kV	Mechanical	Clamp failure	Porcelain	2009	47
CBTS-FTS 1 66kV	Electrical	Flat	Porcelain	2012	44
YPS-ROTS 8 220kV	Mechanical	Bridge Clamp failure	Glass	2013	48
HYTS-APD 2 500KV	Manuf. defect	Degradation of the Fibre Glass core due to moisture ingress into the sheath.	Polymeric	2017	9
HYTS-APD 2 500KV	Manuf. defect	Degradation of the Fibre Glass core due to moisture ingress into the sheath.	Polymeric	2019	10
YPS-YWPS A 220KV	Mechanical	Bridge Clamp failure	Porcelain	2020	50
HWTS-SMTS 2 500kV	Mechanical	Pin Failure	Porcelain	2024	54

Table 4: Insulator Failure Details

The following observations are based on recorded major failures:

Out of the failure events, 9 involved glass insulators, 8 were porcelain, and 2 were polymeric. Recent replacement initiatives have primarily focused on the glass insulator fleet, resulting in a decrease in their numbers. A limited quantity of older glass units remains operational and are continuously monitored. There have been no glass failures reported in the past ten years, with most existing units assessed as being in good or fair condition.

Figure 7 illustrates the distribution of insulator ages at the time of failure, along with the corresponding types.

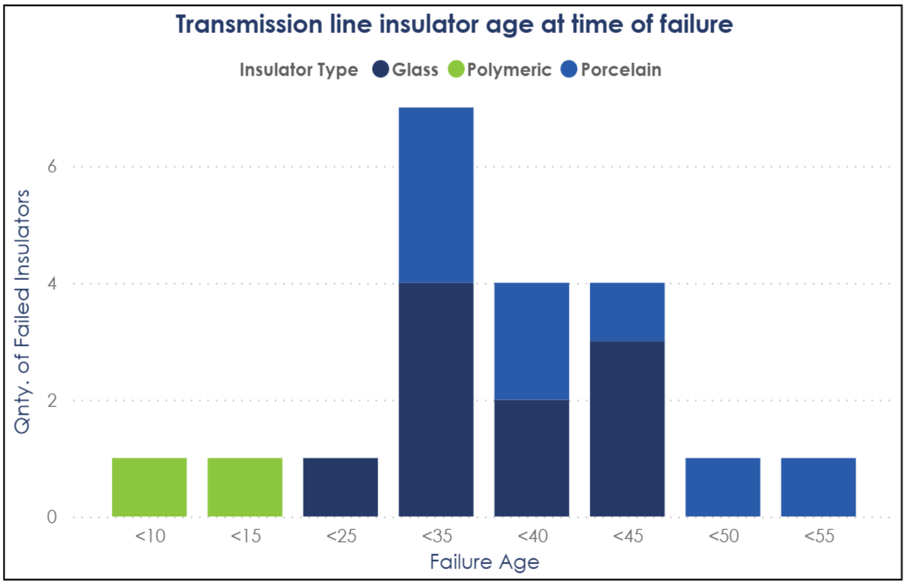


Figure 7: Transmission line insulator age at time of failure

The two failures associated with the polymeric cohort failed after a decade of service life in the corrosivity 3 region at Portland.[7] This was a manufacturing quality defect and also indicates that polymeric insulators may be more vulnerable in aggressive environments (e.g. corrosivity 3 region) and may require earlier intervention. It also highlights the value of good specification, reputable suppliers, and robust quality control processes for new insulators. There have been no polymer failures in medium or low corrosivity zones, the oldest now is at 19 years.

The remaining sixteen functional failures were all observed on porcelain and glass insulators aged between 37 and 54 years, at an average age of 42 years, and with the majority located in Corrosivity Zone 2 (Medium). The most common failure mode, accounting for more than half of the cases, was mechanical failure, primarily due to pin corrosion, followed by hardware corrosion and fitting wear.

These findings underscore the need for closer assessment and timely intervention for porcelain and glass insulators approaching 40–50 years of service, particularly those situated in higher Corrosivity Zones 2 and 3. To proactively manage failure risk, it is essential to prioritise these older assets for enhanced inspection, supported by non-outage-based diagnostic techniques that reduce subjectivity in condition assessments and enable responsive, planned replacements.

A key challenge is the large volume of ageing insulators now within this critical age bracket in higher corrosivity zones. A significant portion of the proposed TRR 2027–2032 replacement program targets this cohort, aligning with asset condition trends and risk mitigation priorities.

The further learning's from the most recent insulator failure in 2024 is discussed in the next section.

[7] The Sediver polymeric insulators were analysed and determined to be inappropriate for the aggressive environment at Portland – these were replaced with NGK insulators.

[C.I.C]

[C.I.C]

[C.I.C] **Insulator pin with corrosion**	[C.I.C] **Insulator pin with excess corrosion removed from area**	[C.I.C] **Insulator pin scrapped to reveal 'uncorroded steel'**
[C.I.C]	[C.I.C]	[C.I.C]

Table 6: C5 [C.I.C] Insulators from the Latrobe Valley

The graph in figure was created following laboratory testing of 10 Doulton insulators of various corrosion levels and associated loss of cross sectional area. It showed the loss of tensile strength associated with loss of diameter through corrosion.

[C.I.C]

Figure 8: [C.I.C] tensile strength testing of Doulton insulators

The association between tensile strength and pin diameter illustrates the need to pro-actively replace corroded insulators.

[C.I.C]

Cracked Seal in Place	Cracked Seal removed to expose Pin
[C.I.C]	[C.I.C]

Table 7: [C.I.C] removed in Metro Melbourne

4.3. Southwest Region Insulators

The [C.I.C] insulators installed in the Southwest of Victoria, extending from Cressy Terminal Station to Heywood and into South Australia, are situated in Corrosivity Zone 2. These insulators are exhibiting increased corrosion, which may be attributed to exposure to coastal salt air, prevailing winds, and limited natural cleaning from rainfall, especially on the pins. This design contrasts with other parts of the 500kV network where different configurations allow for better self cleaning. Approximately 72% of the [C.I.C] insulators, and their hardware, between TRTS and HYTS are currently assessed as being in C5 condition. Examples of C5 insulators are shown in Table 8 below.

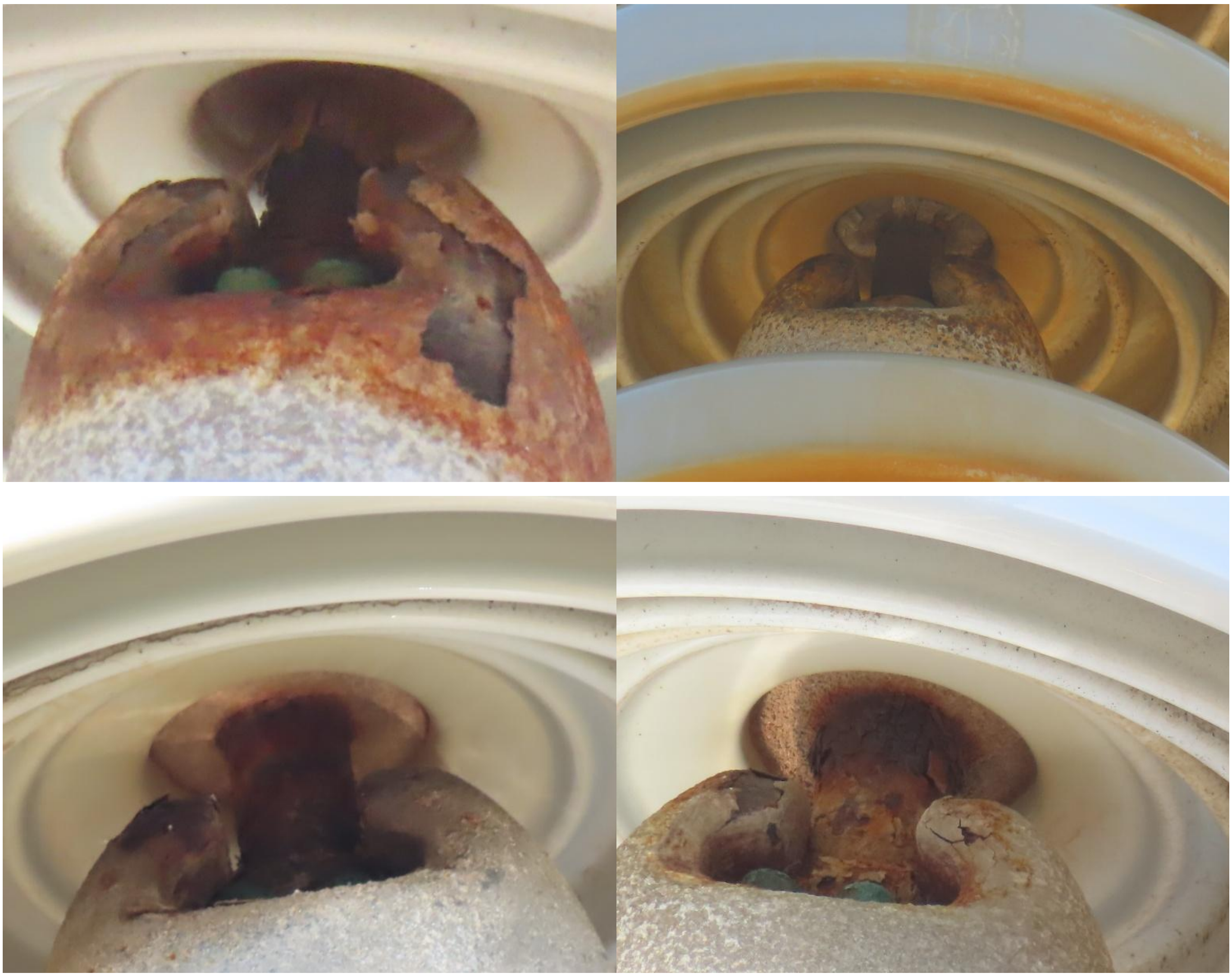


Table 8: [C.I.C] Insulator pins with severe corrosion in south-west

Section 3.2.1 includes a discussion on corrosivity zoning in the Southwest, while Section 3.3.1 compares insulators of the same type and age in the Latrobe Valley and Southwest regions both nominally classified as Zone 2. [C.I.C] insulators in the Latrobe Valley, which are 14 years older at 58 years, are still in better condition, with only 2% assessed as C5.

The Southwest environment corrosion tends to accelerate once galvanising is depleted. During inspections in 2019–2020, most insulators and hardware in the region were assessed as C3 or C4 (light rust or rust spots). By the 2025 inspection, these had progressed to predominantly C4 and C5 condition. In particular, inspections from TRTS/MOPS through to HYTS have identified locations where corrosion has reached 'suspended failure' i.e. defect status, requiring prioritised replacement through maintenance or early intervention projects.

This advanced corrosion of [C.I.C] insulators on the 500kV and 275kV lines in the Southwest is consistent with previous experience. Bulk replacements have already been carried out on other southwest line, specifically the 220kV lines, on the MLTS–TGTS and TGTS–BBTS in 2010 and 2020 respectively, where insulators were replaced at a similar age (around 45–50 years) and condition.

4.3.1. 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 to manage the effects of corrosion in a prudent manner. There is a total of three corrosivity zones used that include low, moderate, and severe.

Table 9 is taken from REF: AS 4312: Atmospheric Corrosivity Zones in Australia. To manage the network three categories were introduced which assigned Low Atmospheric Corrosivity Zone as Corrosivity Zone 1, with Medium Atmospheric Corrosivity as Corrosivity Zone 2, and High Atmospheric Corrosivity as Corrosivity Zone 3.

The current values of the corrosion rate, as μm per year are shown below.

AUSNET CORROSIVITY ZONE	CORROSION RATE, μM / YEAR	AS 4312 CORROSIVITY ZONE
1 (Low)	1.3 to 25	C2
2 (Medium)	26 to 50	C3
3 (High)	51 to 80	C4

Table 9: Corrosivity Zones as used in [C.I.C]

Figure 9 shows the proportion of transmission line insulators located in each of the three corrosivity zones. A map displaying a spatial view of transmission line assets within the three corrosivity zones is included in Appendix B.

From the figure, 45.11% of the transmission line insulators are situated in AusNet's Corrosivity Zone 1 (Low), while approximately 54% are in the Corrosivity Zone 2 (Moderate) and only 0.4% are in the severe Corrosivity Zone 3.

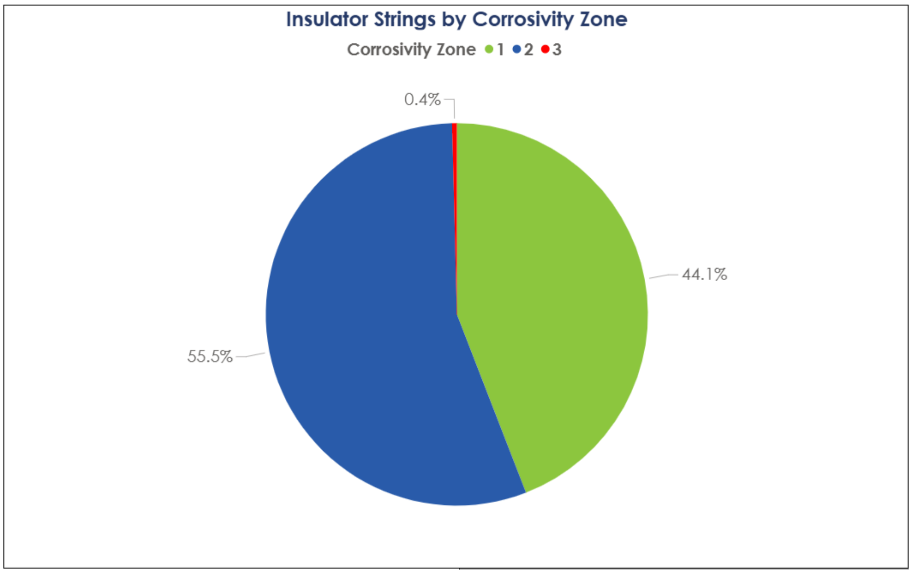


Figure 9: Insulator strings by corrosivity zone

Twenty structures on the Portland side of HYTS–APD 500 kV lines are in severe Corrosivity Zone 3. These circuits supply power to an aluminium smelter plant situated at Portland on Victoria's Southwestern coast. Heavy corrosion of porcelain insulators on these lines prompted their early replacement in 2007 after only 26 years of service. This is also the location where two polymeric insulators failed after only 10 years of service life, and four polymeric insulators were found defective with elevated temperatures in its core. All these insulators were from the same manufacturer [C.I.C] which have since been replaced with an [C.I.C] brand insulator, considered more resilient to this severely corrosive environment.[8]

Corrosivity Zone 2 encompasses a broad geographic area, and recent observations suggest it can be further subdivided into distinct higher and lower corrosivity regions. Notably, insulators located in the southwest region from Cressy Terminal Station through to Heywood and into South Australia are deteriorating at a noticeably faster rate than those in the southeast region, such as the Latrobe Valley, despite both being classified within the same zone.

This variation is likely driven by differing pollution sources. The southwest region is subject to salt-laden air and prevailing coastal winds, which contribute to accelerated corrosion. In contrast, the southeast, particularly the Latrobe Valley, saw industrial pollution which may have declined in recent years with industry shutdowns, contributing to slower insulator degradation.

Additionally, insulator orientation is likely to play a role in pollution build up. Vertical insulators, as used only in the southwest 500kV network, are less effective at shedding surface contaminants via rainwater compared to the V-string arrangements used in the southeast and metropolitan areas, as these benefit from better natural cleaning.

The higher pollution levels in the southwest and in Latrobe Valley were considered during the original design phase, where additional insulator string lengths are installed to compensate for the increased contamination and maintain electrical performance.

[8] To assure supply reliability, circuit 1 has Maclean insulators while circuit 2 now has NGK insulators.

5. Asset Health

Condition of transmission line insulators is assessed during regular detailed inspections which are conducted at 3, 6 or 9 yearly intervals. Inspection frequency is depending on various factors such as corrosivity region, criticality of public location and the market or customer criticality of the line.

Insulators and their hardware are assigned a condition grade from scale from C1 to C5 based on their corrosion, pollution and physical condition. Table 10 outlines condition grades for insulators against corrosion and pollution, with a description against each grading parameter. More detail is described in REF: LPP 09-06: Condition Assessment of Overhead Lines. Insulators or their associated hardware assessed to have gone beyond a condition 5, such as more extreme corrosion, are raised as corrective maintenance defects for shorter term replacement.

Condition grades of insulators are considered along with other factors such as type, corrosivity, and failure modes when taking decisions with respect to managing the asset.

Remaining life is the estimated time, expressed as a percentage of expected life, an insulator at that condition score has left before it would need to be replaced to maintain safety and reliability of the network.

CONDITION SCORE	CONDITION DESCRIPTION	PORCELAIN & GLASS DISC	POLYMERIC LONG ROD	REMAINING LIFE
C1	Very Good	As new. No issue identified	As new. No issue identified	95%
C2	Good	Glazing of disc dulled or gone	Minor discoloration on shed or sheath, First rust.	85%
C3	Average	First rust or first sign of wear	Moderate discolouration of sheds or sheath, Light rusting	60%
C4	Poor	Light rust, or <10% wear	Minor flashover damager or Minor damage to sheds clear of sheath or Extensive blackening of sheds or sheath, Extensive surface rusting.	25%
C5	Very Poor	Extensive surface rust of <20% wear or minor chips or minor flash/arcing damage	Minor tracking damage to sheath, Sheds split or torn up to sheath, Pellets embedded in sheath Flashed with no evidence of damage to end seals Animal attack, <10% of sheds lost, Flaking rust	<15%

Table 10: Condition score scale

C1

C2

C3

C4

C5

Table 11: C1 to C5 Insulator Pins

5.1.1. Insulator Condition Profile

Figure 10 below shows the population and type of transmission line insulators in their assessed condition score. Trends are overall positive with just 50% of the fleet with in C2 and a significant portion within the C1 and C3 allocations. However, it is important to recognise the portion of porcelain types that are in C4 and C5.

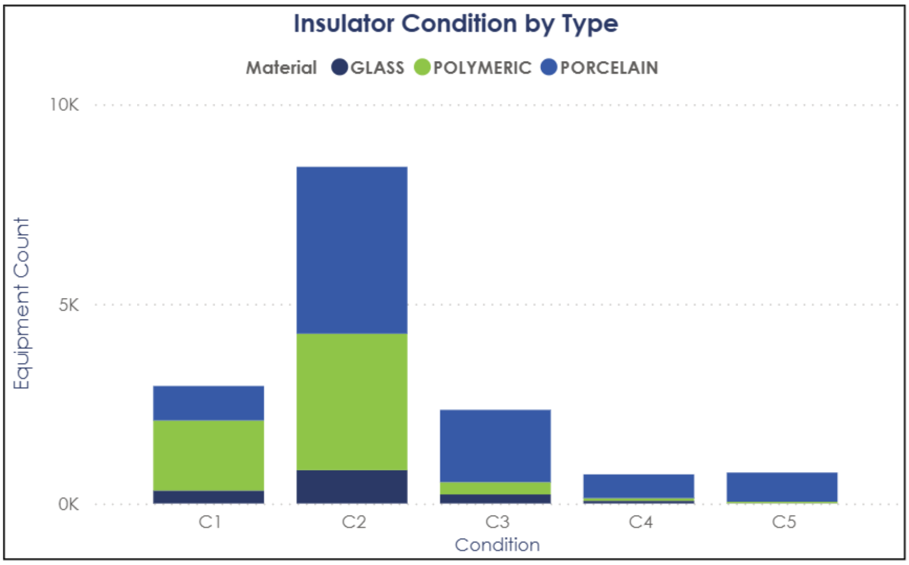


Figure 10: Insulator condition by type

- **Glass insulators** tend to be in better condition C1–C3, with a few C4.
- **Polymeric insulators** are predominately found in C1 to C3 condition with some C4 due to bird or flash over damage.

- **Porcelain** is predominately in C2 and C3 condition, however a significant amount is in C4 and C5 condition due to their type and location in Corrosivity Zone 2 areas. Appendix B shows two maps demonstrating the corrosivity regions as well as the spatial view of the proposed TRR program. A strong correlation exists between Corrosivity Zone 2, typical age and the rated C5 insulators can be observed.

Figures 11 shows how corrosivity is the leading factor over age in insulator replacement. Most notably is the peak in the insulators installed in 1969 and 1981 where those that are in a corrosivity 2 region are needing to be replaced in large volumes compared to insulators of the same age and material type in a corrosivity 1 region. Note insulators in Corrosivity Zone 3 were replaced in 2006 and so are not shown.

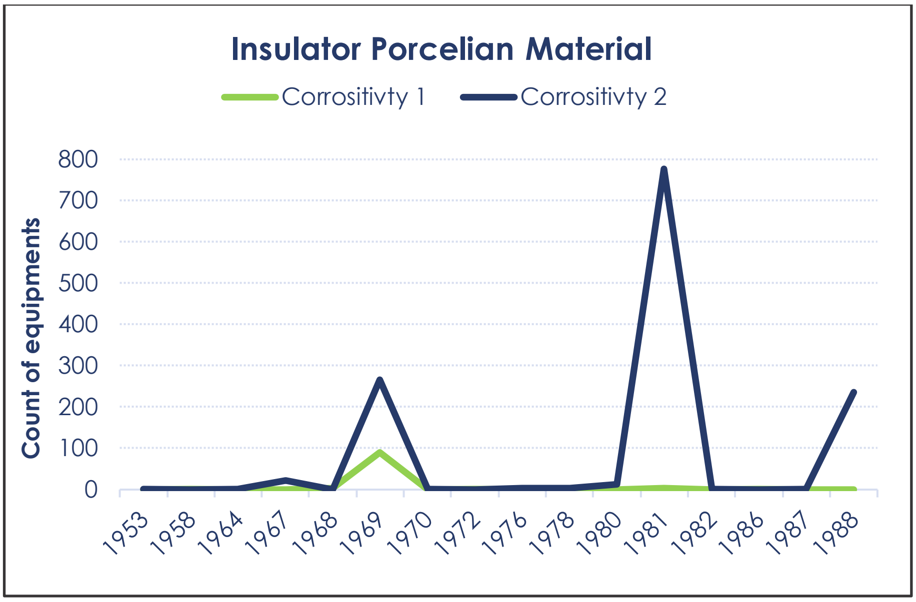


Figure 11: Age of insulators selected for replacement. Insulators in Corrosivity Zone 2 in greater need of replacement.

Figure 12 also demonstrates that regional corrosivity effect and the effect of the insulator arrangement (insulator orientation) as the leading factors over age in insulator replacement. The graph shows the condition assessment of the same 500kV [C.I.C] Insulator type, all installed in 1980/81and all reaching their 45-year regulatory defined life by the 2027 to 32 period. The insulators in the southeast are located on the HWTS-ROTS, HWTS-CBTS lines in a V-string arrangement. Compared to the insulators in the southwest on the MLTS- HYTS lines in I-String arrangement.

Given the more advanced corrosion observed in the southwest, the current TRR period includes the commencement of replacement of some C5-rated insulators in this region. The remaining C4 and C5 insulators in this region are proposed for replacement during the 2027–2032 TRR period, aligning with asset condition and risk management priorities. Note the same 45-year old [C.I.C] insulators and 55-year old [C.I.C] insulators in the southeast are not proposed for replacement consistent with our view that a condition-based approach represents the most prudent asset management strategy.

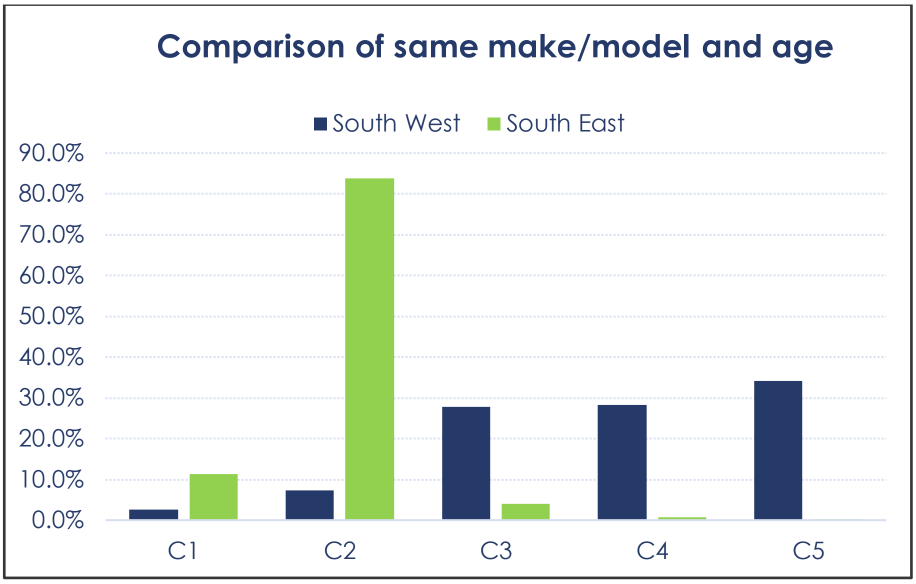


Figure 12: 500kV [C.I.C] Corrosion - Southwest vs Southeast

The majority of C5 insulators in the network belong to the porcelain material type which consists of two main brands, those being [C.I.C] and [C.I.C], the [C.I.C]and [C.I.C] are discussed further in section 4.3 & 4.4.

6. Related Matters

6.1. Polymeric Insulators

- Research to develop cost effective techniques for assessing the condition and the remaining expected service life of polymeric insulators is ongoing.
- The performance and remaining service potential of polymeric insulators which have been subjected to extreme heat from bushfires need verification by sampling and testing.
- Polymeric insulators which have suffered flash-over damage along mountainous areas, where there is high lightning activity, are often left undetected due to a combination of ineffective protection fault location and visual identification.
- New and reliable techniques to determine the dielectric performance of polymeric insulators which had suffered from flashover damage are required to promote the safety of line workers prior to doing live-line replacement of the string.

6.2. Live Line methodologies

- Due to the criticality of the relevant circuits and large volume of works proposed in the 28-32 Regulatory period, live-line methodologies will be adopted, where safely applicable, as the number of outages otherwise required would have severely impeded deliverability of the program. If feasible, work will be scheduled during outages that align with other program outages, however increasing network congestion and reliability constraints are making it difficult for AusNet to take outages particularly on the southwest corridor.
- Due to safety and customer impacts, a 'run to failure' approach can never be adopted for Transmission line insulators.

6.1. Victorian Transmission Planning (VTP) Overlap

Two Victorian Transmission Planning (VTP) projects coincide with insulator replacement programs.

Murra Warra – Horsham – Ballarat 220kV Lines

AusNet has assessed the replacement of 5 insulator locations on the BATS–WBTS and BGTS–HOTS lines during 2027-32, considering the VTP project due for completion by 2035.

As VicGrid plans to rebuild the lines within 3 years of the TRR program and AusNet anticipates the rebuild will take a number of years to deliver, replacing the insulators in the current TRR program would not be operationally efficient or economically justified. As the insulators are condition C4 and in a low corrosivity region, the latest risk assessment shows that delaying replacement to 2033 is manageable.

Mt Beauty – Eildon 220kV Line

AusNet has reassessed insulator replacement on the MBTS–EPS line due to the planned 2029 VTP clearance remediation to uprate the line. AusNet concludes that these activities are distinct, based on the assumption that raising the conductor is unlikely to affect Strain towers, and the single insulator location identified for replacement is located on a strain tower. AusNet will include this replacement in the TRR submission.

7. Proposed Program of Work

7.1. Approach

7.1.1. Risk

AusNet's asset management decisions within the transmission network are guided by a risk based approach, ensuring alignment with our organisational risk appetite. For insulators, addressing risk over time requires replacement and maintenance. Project justifications are based on current and extrapolated risk.

The risk of each asset is calculated as the product of Probably of Failure (PoF) of the asset and the Consequence of Failure (CoF). This risk is then extrapolated into the future accounting for forecast changes in PoF and CoF.

AusNet's approach to asset risk management is detailed in REF: AMS 01-09 Asset Risk Assessment Overview.

7.1.1.1. Asset Risk Quantification Methods

Probability of Failure

The PoF for transmission line insulators is determined using health score model calculations, incorporating three key factors:

- Asset physical condition score
- Corrosion Zone
- Insulator material type

Asset managers use the health score models to calculate the conditional PoF for the next one year. The initial and following years of PoF are calibrated and calculated using Weibull Distribution model. AMS 01-09 provides details to logic and parameters of the Weibull models.

Consequence of Failure

AusNet assigns a monetised value to CoF which provides an economic basis of calculating potential consequence.

The cost of failure is assessed through four key lenses: Safety, Environment, Customer/Market Impact and Financial. These lenses provide a structured view of the potential impacts resulting insulator failure, resulting in outages and/or line drops. Table 12 summarises the focus of each lens:

CONSEQUENCE LENSES	DESCRIPTION
Safety	Threat to health and safety of the public and employees
Environment	Bushfire damage
Customer / Market	Loss of supply to customers Impact to on energy market
Financial	Emergency response and repairs Asset replacement costs Collateral damage

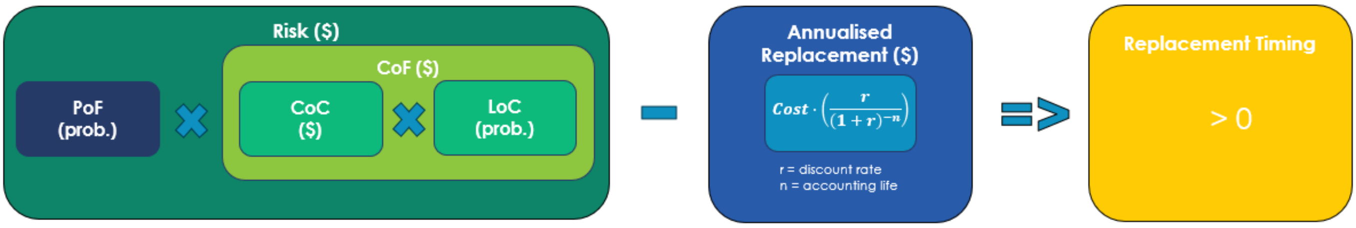
Table 12: Consequence lens description

7.2. Economic Viability

7.2.1. Economic Model

Asset Managers use the calculated risk based on PoF and CoF outputs to identify optimal intervention years, balancing technical feasibility with economic efficiency. These outputs are incorporated into an economic model. The economic model demonstrates the year when the calculated annualised risk is higher than the annualised replacement cost, and as such when the asset becomes economically viable to replace. The concept is illustrated below.

The economic model is producing a structured approach for each asset in the fleet. The economic model for the justified replacement program is available in asset class economic model REF: *ANT – TRR 2028-32 Asset Replacement Economic Model – Transmission Line Insulators.*



7.3. Engineering Validation

Following the generation of economic models and asset health models, a structured validation process is undertaken by Senior subject matter experts. This step is intended to that model outputs are interpreted within the broader context of engineering intervention options, operational experience, and current asset condition knowledge.

Assessment as to whether the asset replacement, refurbishment, change in maintenance regime or no action are the most reasonably practicable choice. This involves verifying condition data, evaluating operational priorities, and considering strategic timing of interventions. Where appropriate, recommendations and alternative actions can be made based on professional assessment.

This validation process complements the use of the economic model. It supports a balanced and accountable approach to asset management, one that upholds technical integrity while remaining responsive to operational realities.

7.4. Proposed Program

AusNet is proposing a targeted insulator replacement program for the next regulatory period. Assets selected for this program have been prioritised using a condition based methodology, underpinned by risk assessments and economic evaluations as detailed in Section 5. These assets have demonstrated increased risk profiles due to their deteriorating condition, necessitating intervention to prevent potential future failures.

Table 13 below presents the recommended program of works for transmission line insulators, formulated through a risk based methodology and consistent with the rationale provided within the economic model, showing the proposed count of insulators equipment locations for the upcoming regulatory period from 2027 to 2032.

ASSET VOLTAGE	TOTAL
500kV	1229
330KV	2
275kV	255
220kV	65
Total	**1551**

Table 13: Proposed program of works by voltage

The primary focus of the program is the replacement of 500kV transmission line insulators, which constitute the largest volume of planned interventions. A total of 1,229 insulator assemblies has been identified for replacement. Many of these assets exhibit advanced stages of corrosion, and their failure would pose a significant risk to market operations due to their critical location on the 500kV backbone network. The majority are located in the southwest region, which is characterised by elevated atmospheric corrosivity. The other major group targeted for replacement includes the deteriorated [C.I.C] 500kV insulator assemblies situated in metropolitan and eastern regions. The need for intervention was substantiated through a comprehensive failure analysis and findings from the early stages of a replacement program, which revealed that a specific design characteristic had been masking the true extent of corrosion, thereby hindering timely maintenance. The 500kV replacement volume represents around 30% of the 500kV insulator fleet, which are predominantly at 45 or 55 years old.

The second most critical asset group comprises the original 275kV porcelain insulators installed on the HYTS–SESS transmission line, which forms a key interconnection between Victoria and South Australia. These insulators are exhibiting significant corrosion, with the majority classified within the C5 condition category. Located in the southwest region, they are subject to atmospheric conditions similar to those affecting the 500kV insulators targeted in the primary replacement program.

Additionally, the program includes a smaller number of insulators within the 220kV and 330kV network due to various C4 & C5 assets on lines with higher safety consequence locations or higher market impacts. The program does exclude C4 insulators on lower risk locations and are expected to be addressed in 2032-38 TRR period.

Overall, the replacement of 1,551 insulator equipment locations means that Ausnet will propose to replace 9.0% of the fleet in the next TRR period. This reflects an increase relative to the current regulatory period, primarily driven by the ongoing deterioration in insulator condition. This marks the first significant scale-up in the volume of 500kV insulator replacements. Despite the increased scope, the replacement volumes remain consistent with those observed during the initial phases of the insulator replacement program on the legacy 220kV network.

Image below shows the spatial location of the insulators by C5 (red) and C4 (Orange) condition insulators in the proposed program of works.

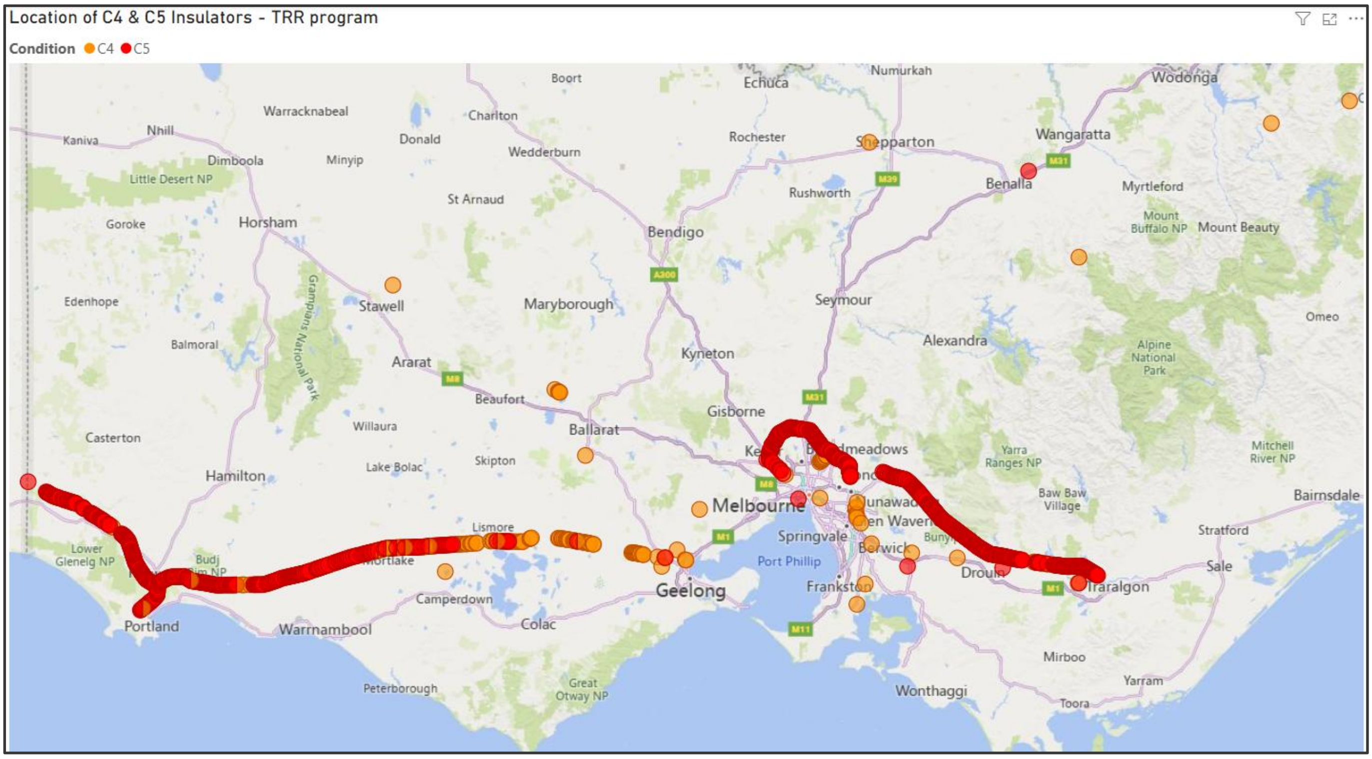


Figure 3: Spatial view of TRR program

8. Asset Strategies

8.1. New Assets

- Current policy is to install polymeric insulators as part of insulator replacement programs.
- Polymeric insulators have been known to be attacked by birds if strung under de-energized conditions. Provision will be made to prevent bird attack during project implementation planning.
- Fail-safe design concepts to be applied for insulation systems on new replacement of transmission line structures adjacent to high risk roadways and railways or proof test all insulator fittings prior to installation on towers across roads and railways.
- 2017 & 2019 polymeric insulator failures highlighted the need for more stringent selection of suppliers[9].

8.2. Inspection

- Continue to assess the condition of transmission line insulators during structure climbing inspections conducted at regular intervals and during the annual line and easement inspections.
- Continue to explore and expand upon the use of technologies such as Remotely Piloted Aerial System (RPAS also known as drones) to conduct visual, thermal and corona inspection of insulators.
- Enhance the current use of Smart Aerial Inspection and Processing (SAIP) technology to identify defective insulators and other line hardware.
- Reiterate the import of all relevant technical asset data including date of installation into [C.I.C] as part of project close-out for insulator replacement projects.
- Continue to use Field Mobile Inspection (FMI) system as the primary means of capturing condition assessment data and include the asset information, i.e. type of insulator and manufacturer, as part of the data capture process.
- Investigate cost effective methods of assessing polymeric insulator condition.

8.3. Maintenance

- Replace defective insulator strings as part of corrective maintenance tasks. Complete string replacement is preferred as it is more economic and safer than replacement of an insulator from within a string of insulators.
- Update SAP with the details of the new insulator installed on the tower as part of the close-out process of maintenance activities.

8.4. Replacement

- Selectively replace 1551 insulator equipment's which are in high consequence areas and in poor/very poor condition between 2027 and 2032. This quantity represents 9.0% of the insulator fleet.
- Live-line replacement methods will be the desired work method due to the large volume of insulators that would otherwise require too many outages and impede deliverability.
- Where opportune works can be done on outages due to other programs of work, potential cost savings and efficiencies can be achieved.

[9] A methodology, based on an international procedure, is being created to test samples collected from the line that had failures. The objective is to confirm if the failures may be connected to the manufacturing process of the insulator, i.e. improper bonding between silicone rubber sheath and fibre glass rod.

9. Resource Reference

No.	TITLE
1	AMS 01-05 Strategic Asset Management Plan
2	AS 4312: Atmospheric Corrosivity Zones in Australia
3	LPP 09-06: Condition Assessment of Overhead Lines
4	AMS 01-09 Asset Risk Assessment Overview
5	ANT – TRR 2028-32 Asset Replacement Economic Model – Transmission Line Insulators

10. Schedule of Revisions

ISSUE NUMBER	DATE	DESCRIPTION	AUTHOR	APPROVED BY
5	22/11/2006	Review and Update	[C.I.C]	[C.I.C]
6	05/02/2007	Review and Update	[C.I.C]	[C.I.C]
7	17/03/2007	Review and Update	[C.I.C]	[C.I.C]
7.1	25/11/2011	Review and Update	[C.I.C]	[C.I.C]
8	13/12/2012	Review and Update	[C.I.C]	[C.I.C]
9	14/8/2015	Review and Update	[C.I.C]	[C.I.C]
10	06/07/20	Review and Update	[C.I.C]	[C.I.C]
11	30/06/2025	Review and Update	[C.I.C]	[C.I.C]

Contact

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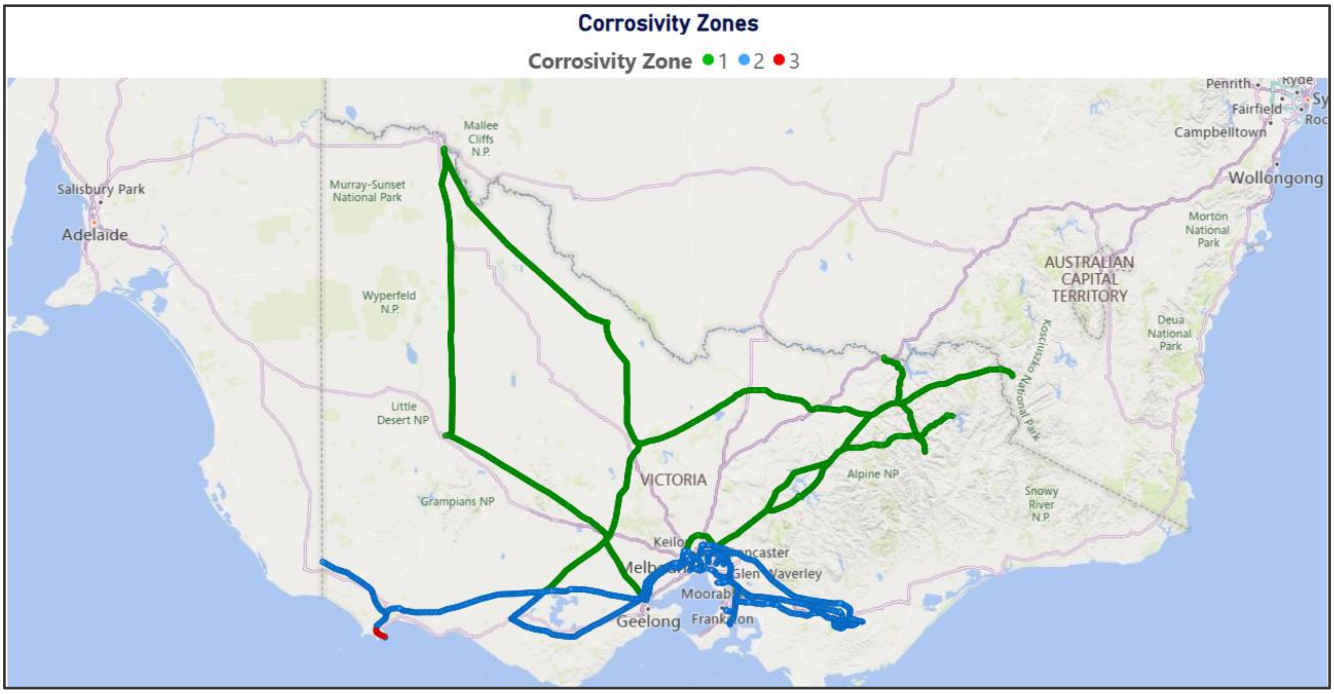
Appendices

Appendix A – Proposed Insulator Replacement Program

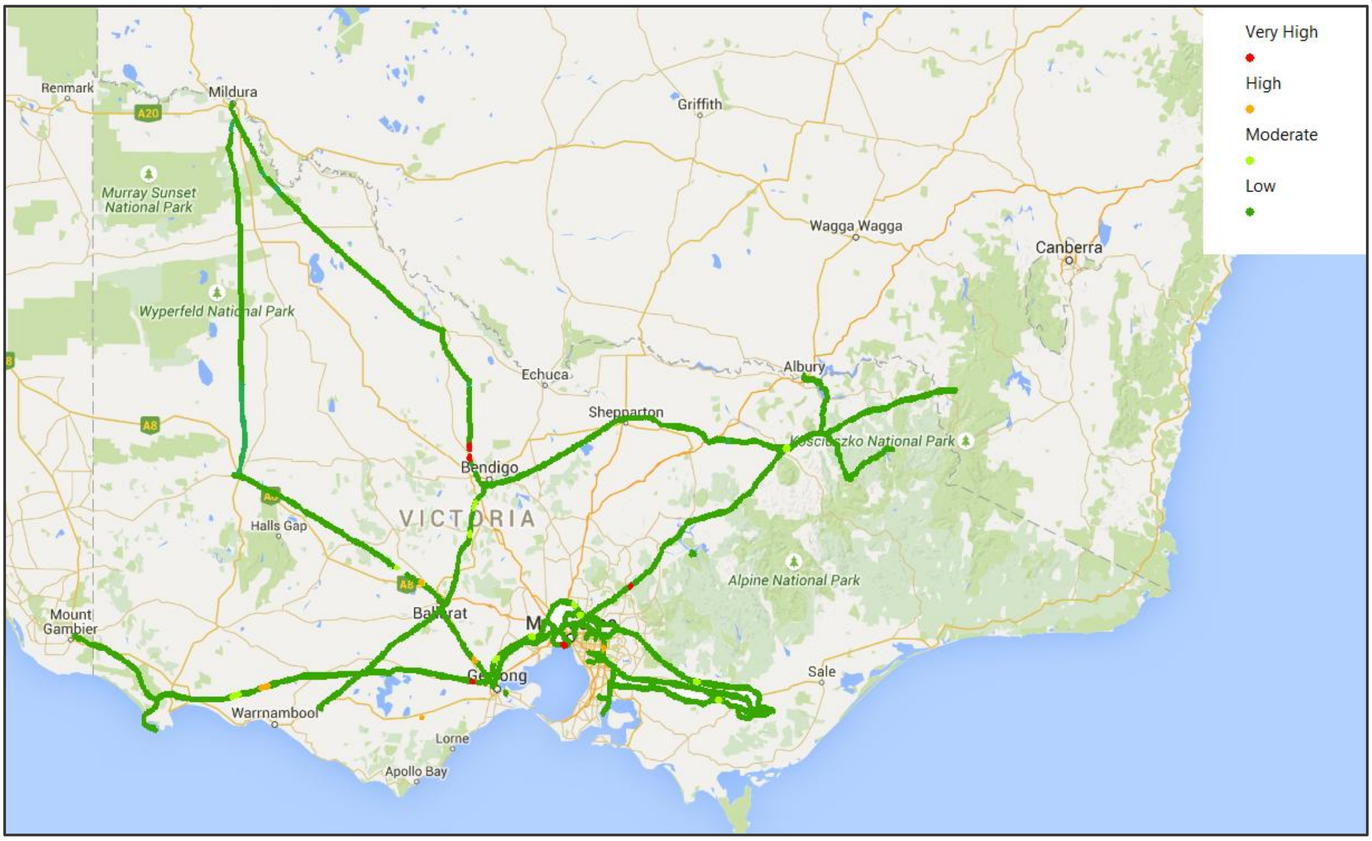
LINE	220KV	275KV	330KV	500KV	TOTAL INSULATOR LOCATIONS
HWTS-SMTS 2				240	240
MOPS-HYTS 2				202	202
HGTS-TRTS 1				201	201
CRTS-MOPS 2				139	139
HYTS-SESS 1		129			129
HYTS-SESS 2		126			126
SMTS-SYTS 2				109	109
TRTS-HYTS 1				102	102
ROTS-SMTS 3				44	44
MLTS-CRTS 1				33	33
MLTS-CRTS 2				32	32
CRTS-HGTS 1				32	32
HYTS-APD 1				30	30
HYTS-APD 2				29	29
HWTS-SMTS 1				23	23
SMTS-TTS 1	12				12
SYTS-KTS				11	11
ROTS-RWTS	8				8
ROTS-TSTS	8				8
YPS-YWPS 4	4				4
BATS-WBTS	4				4
MLTS-GTS 1	3				3
CBTS-TBTS 2	3				3
ERTS-CBTS 1	2				2
YPS-YWPS 3	2				2
ERTS-CBTS 2	2				2
MLTS-GTS 2	2				2
YPS-ROTS 6	2				2
MSS-DDTS 1			2		2
KTS-GTS 1	2				2
HWPS-ROTS 1	2				2

DDTS-SHTS	2				2
SYTS-MLTS 1				1	1
YPS-ROTS 8	1				1
BATS-BBTS	1				1
MBTS-EPS 1	1				1
ROTS-RTS 1	1				1
HWTS-ROTS 3				1	1
MRTS-KMTS	1				1
SHTS-BETS	1				1
YPS-ROTS 7	1				1
MLTS-TGTS	1				1
NPSD-FBTS	1				1
FBTS-BLTS	1				1
BGTS-HOTS	1				1
BBTS-TGTS	1				1
Grand Total	**70**	**255**	**2**	**1229**	**1551**

Appendix B – Corrosivity Zones on the Victorian Transmission Network



Appendix C – Bushfire Consequences on the Victorian Transmission Network



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