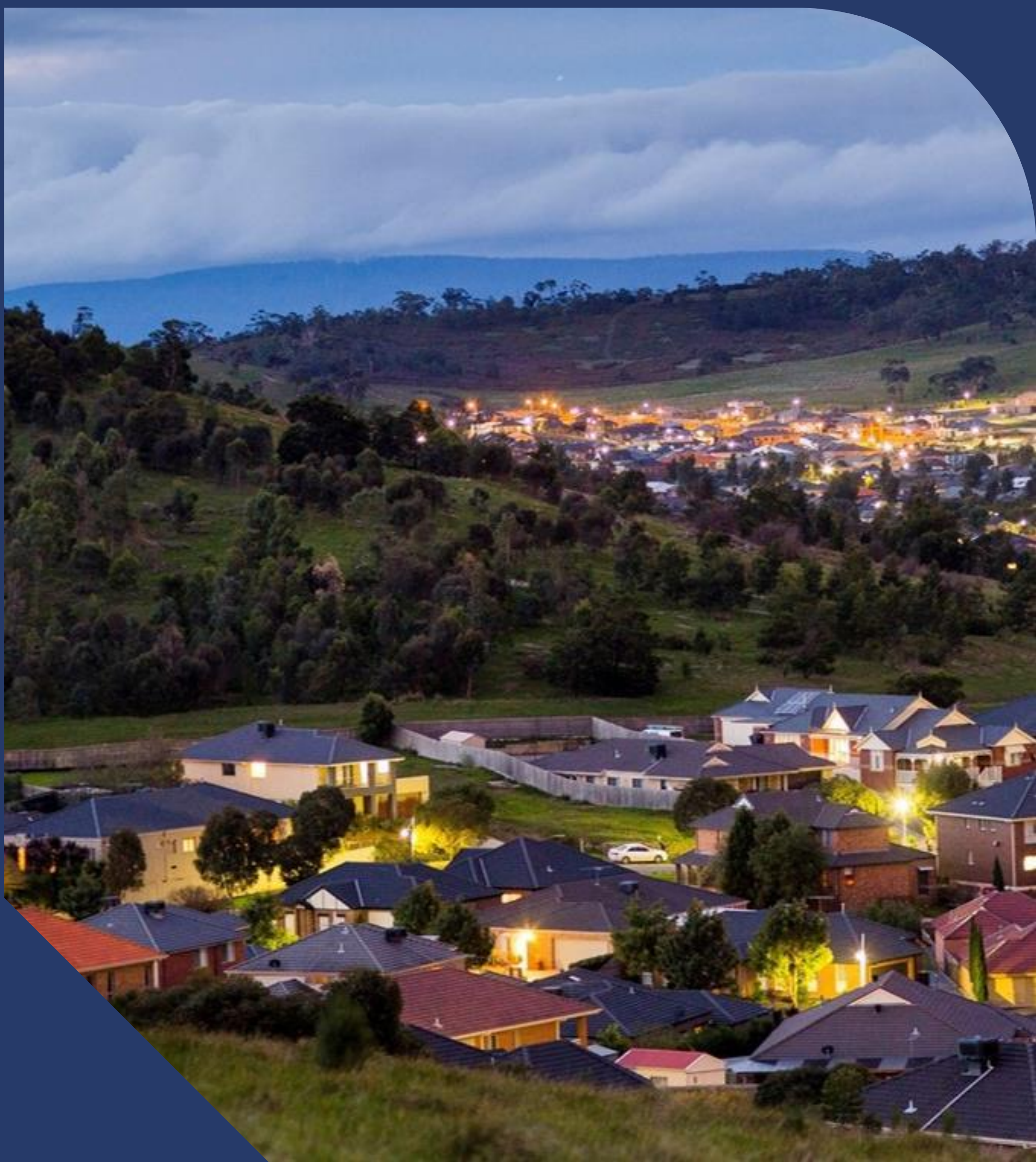
Power Transformers and Oil Filled Reactors

Asset Management Strategy



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AusNet

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Abbreviations and Definitions

TERM	DEFINITION
AMS	Asset Management Strategy
COF	Consequence of Failure
POF	Probability of Failure
PT	Power Transformer
RIN	The Regulatory Information Notice
ZK	Work order Notifications associated with failures (unplanned power interruptions)
ZA	Work order Notifications associated with corrective actions from planned inspections
OLTC	On Load Tap Changer
ONAN	Oil Natural Air Natural
ODAF	Oil Directed Air Forced
OIP	Oil Impregnated Paper
SRBP	Synthetic Resin Bonded Paper
RIP	Resin Impregnated Paper
RIS	Resin Impregnated Synthetics

1. Executive Summary

This document outlines AusNet's asset management strategy for power transformers and oil-filled shunt reactors within the regulated electricity transmission network. It details the approach to inspection, maintenance, monitoring, and targeted replacement to support ongoing compliance with regulatory standards and responsible, economically justified lifecycle management.

The strategy addresses the challenges presented by a diverse and ageing fleet of 174 power transformers and 13 oil-filled reactors, comprising: 330kV and 500kV Shared network transformers in both single-phase and three-phase configurations, and Customer connection transformers at 220kV and 66kV as three-phase units.

A risk-based assessment has been undertaken, focusing on the probability of failure and the consequences of failure, including community impact, safety, environmental, and market considerations. This assessment supports a targeted wholesale replacement program for high-risk power transformers and shunt reactors between 2027 and 2032, delivered through a major station replacement program, and a targeted asset replacement of individual components in poor condition, such as Bushings, Phase Isolated Bus (PIB), Winding Temperature Indicators (WTIs), and Transformer Management Systems (TMS).

The strategy emphasises proactive management through ongoing refurbishment programs, such as the sulphur-contaminated soil remediation initiative, scheduled preventative maintenance, non-invasive condition monitoring, and periodic electrical testing. It also addresses challenges related to technical obsolescence and limited OEM support. The plan aims to satisfy stakeholder expectations for safety, reliability, cost-effectiveness, and environmental responsibility are consistently met.

1.1. Asset Strategy Summary

AusNet's asset strategy for power transformers and shunt reactors adopts a proactive approach to risk management, safety, and reliability, delivered through a focused combination of replacement, refurbishment, and maintenance initiatives. The strategy prioritises the replacement of high-risk units and the extension of transformer service life through targeted interventions. This work towards stakeholder expectations for cost efficiency, safety, reliability, and environmental stewardship are consistently met in a prudent and effective manner.

Key components identified for replacement include bushings with advanced deterioration, specifically [C.I.C] 220 kV and 66 kV OIP bushings, as well as [C.I.C] 500 kV and 220 kV OIP bushings (see Section 5.3.1), due to their elevated failure risk. The strategy also encompasses the replacement of faulty winding temperature indicators (see Section 5.3.2) and outdated Transformer Management Systems (see Section 5.3.3) to maintain safe and reliable operation of the transformer fleet.

Ongoing refurbishment efforts focus on the active oil regeneration program, targeting transformers affected by corrosive sulphur in oil, which can accelerate degradation of copper windings and OLTC selector silver contacts. This initiative is underway, with completion anticipated in the upcoming TRR 27-32 period. Additional refurbishment activities are aimed at mitigating specific risks, such as Phase Isolated Bus [PIB] upgrades at Hazelwood Terminal Station (A2, A3 & A4, see Section 5.3.4), oil reclamation, leak management, and corrosion prevention for tanks and coolers.

Maintenance continues to be driven by scheduled preventative tasks, leveraging standardised work instructions, ongoing updates to SAP measurement points, and adaptive planning based on observed deterioration trends. Lifecycle risk management is further strengthened by regular reviews of strategic spare holdings and dynamic inventory adjustments as OEM support diminishes, coupled with salvaging usable parts from retired equipment to support ongoing maintenance requirements.

This integrated, risk-based asset management strategy supports AusNet's power transformer and shunt reactor fleet is operated and maintained to the highest standards, upholding stakeholder objectives for safety, reliability, cost-effectiveness, and environmental responsibility.

2. Introduction

2.1. Purpose

The purpose of this document is to outline the inspection, maintenance, replacement and monitoring activities identified for economic lifecycle management of the fleet of terminal station power transformers and oil filled reactors. The document is intended to communicate the basis for asset management decisions.

In addition, this document forms part of the AusNet Management System for compliance with ISO 55000 and relevant regulatory requirements. The document demonstrates responsible asset management practices by outlining economically justifiable outcomes.

2.2. Scope

This strategy includes:

- Regulated Transmission Power Transformers with nominal primary winding voltage ranging from 66kV to 500kV.
- Oil Filled Reactors with nominal primary winding voltage ranging from 66kV to 500kV.

The strategy excludes:

- Unregulated Transformers
- Station Service Transformers (AMS 10-52 Auxiliary Power Supplies)
- Special Purpose Transformers (e.g. Auxiliary Transformers, Neutral Earthing Transformer)
- Air Core Reactors

2.3. Asset Management Objectives

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

Transformers are required to transfer power between circuits of different operating voltages. The power transformer fleet has nameplate ratings ranging from 30MVA to maximum continuous power ratings of 1,000MVA.

3.2. Population

Section 5.2 of the Regulatory Information Notice (RIN) for the 2024-2025 financial year reports a total of 174 power transformers and 13 oil filled reactors. Of the listed transformers there are 46 single phase tanks that constitute 12 three phase transformer banks and 10 single phase spares. The population figures presented below account for three-phase transformers and transformer banks as distinct transformer functions, with percentage distributions calculated based on these functional classifications.

3.2.1. Power Transformers

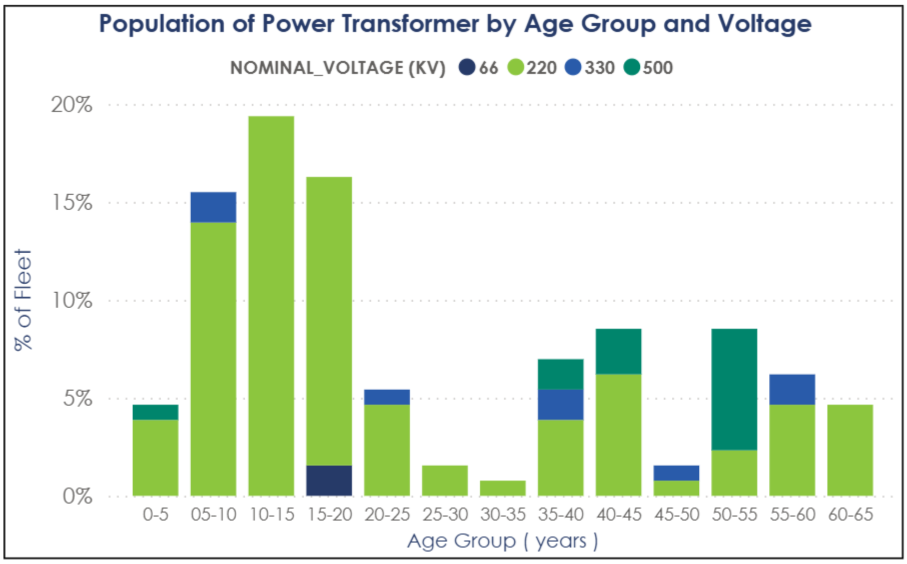


Figure 1: Population of all Power Transformer by Age Group and Voltage

Figure 1 shows the distribution of power transformers by age and voltage, reflective of both historical installation practices and more recent asset replacement strategies. Notably, older transformer units tend to be concentrated at higher voltage levels, corresponding to legacy infrastructure that has remained in service for several decades. Key components such as bushings and winding temperature indicators (WTIs) have typically been replaced to extend service life. In contrast, newer installations are predominantly found within the 220kV class, underscoring the impact of targeted renewal programs and ongoing efforts to enhance network reliability.

Transformers featuring a secondary winding of 66kV or lower that supply distribution network operators (DNOs) under a connection agreement are classified as Connection Transformers. This group includes the “B (220/66kV)”, “L (220/22kV)”, “X (330/66kV)”, and “U (66/22kV)” types, which are presented relative to age and voltage in Figure 2.

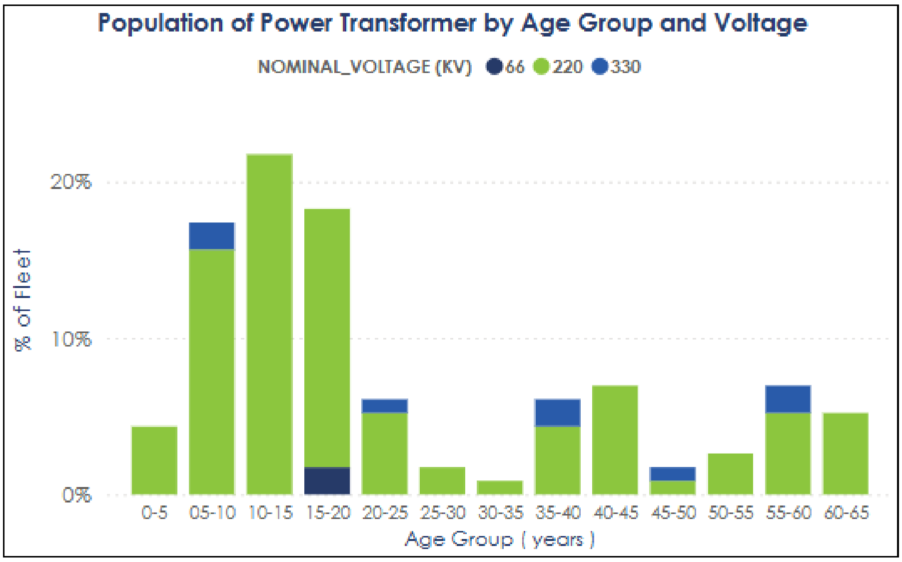


Figure 2: Population of Connection Transformer by Age Group and Voltage

Transformers with nominal secondary winding voltage of 220kV or above contribute to the reliable function of the national electricity market (NEM) – they are main tie transformers within the shared network. They are referred to throughout this document as Shared Transformers and include "A (500/220kV)", "F (500/330kV)", "M (500/275kV)" and "H (330/220kV)" transformers. The population against age and voltage for shared transformers are plotted in Figure 3.

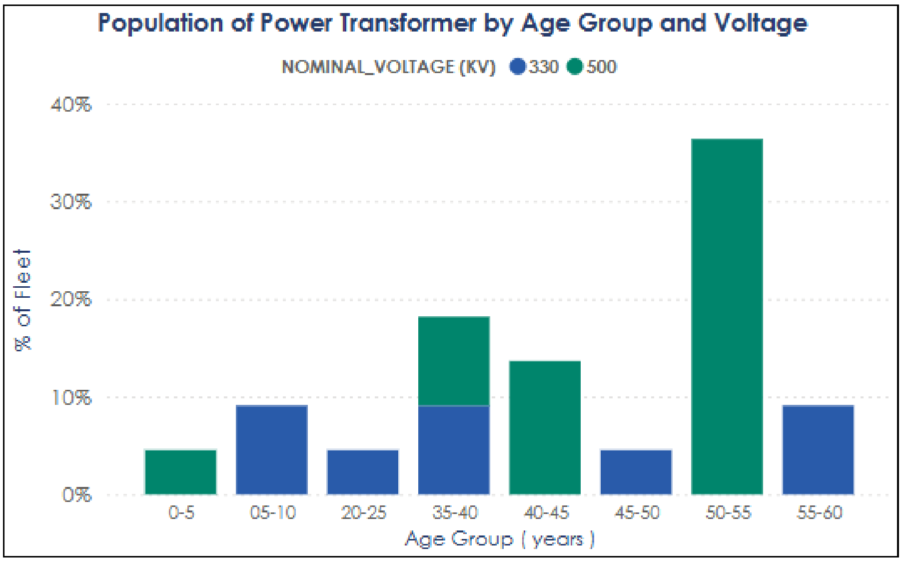


Figure 3: Population of Shared Transformer by Age Group and Voltage

Similarly, Figure 4 plots transformers against age group and winding configuration – three phase transformers or single-phase banks.

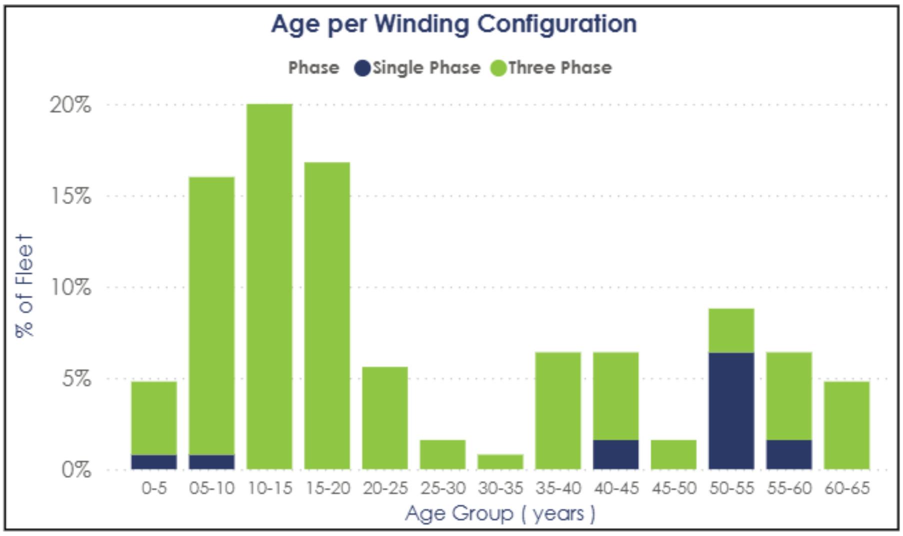


Figure 4: Population of all Power Transformers by Age group and Winding Configuration

Figures 1, 2, and 3 illustrate that the 220kV transformer fleet has a significantly younger age profile compared to the Shared transformers. This is primarily due to progressive replacement projects undertaken in previous TRRs, which targeted 220kV units identified with short-circuit concerns specifically with [C.I.C] units, [C.I.C] units from the 1970s–80s, and [C.I.C] units from the 1970s–80s.

Additionally, a bushing replacement program was implemented to address the high-voltage bushings on multiple Shared transformers including KTS A transformers, mitigating catastrophic failure risks and extending operational life. However, the condition of the core and windings is irreversible and has deteriorated beyond their 45-year design life. This substantiates the need for full transformer replacement during TRR 27–32.

3.2.2. Oil Filled Reactors

The fleet of oil filled reactors are plotted against age and voltage in Figure 5:

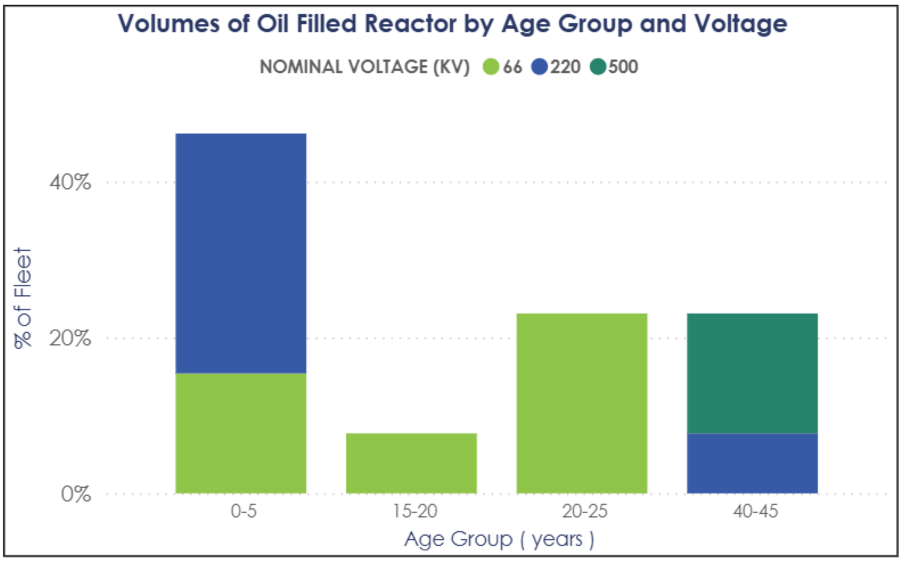


Figure 5: Population of Oil Filled Reactors by Age Group and Voltage

Generally, oil-filled reactors are newer than power transformers. Decreasing minimum demand has led AEMO to increase shunt reactor installations, explaining the recent rise in new units. The 40–45 year column includes two 500kV and one 220kV shunt reactors at MLTS, all nearing end of life; consequently, replacements for one 500kV and one 220kV reactor are planned for the TRR period 27–32. Decisions on in situ replacement or relocation of the 500 kV reactor will depend on joint planning with AEMO Victorian Planning.

3.2.3. Manufacturers

Power transformers and oil-filled reactors differ from larger groups of assets because each has its own specific electrical design and internal structure. The electrical performance is primarily determined by the requirements of the local network, with physical layout playing a secondary role. Where feasible, the physical arrangement and component selection are typically standardised for each voltage class.

3.2.4. Vector Group

The fleet of power transformers varies by primary and secondary voltages, manufacturers, and 'vector groups' as shown in Figure 6. The configuration of three-phase windings in a transformer determines its vector group classification. The largest vector group, YNyn0d1, is the 220/66kV connection power transformer fleet.

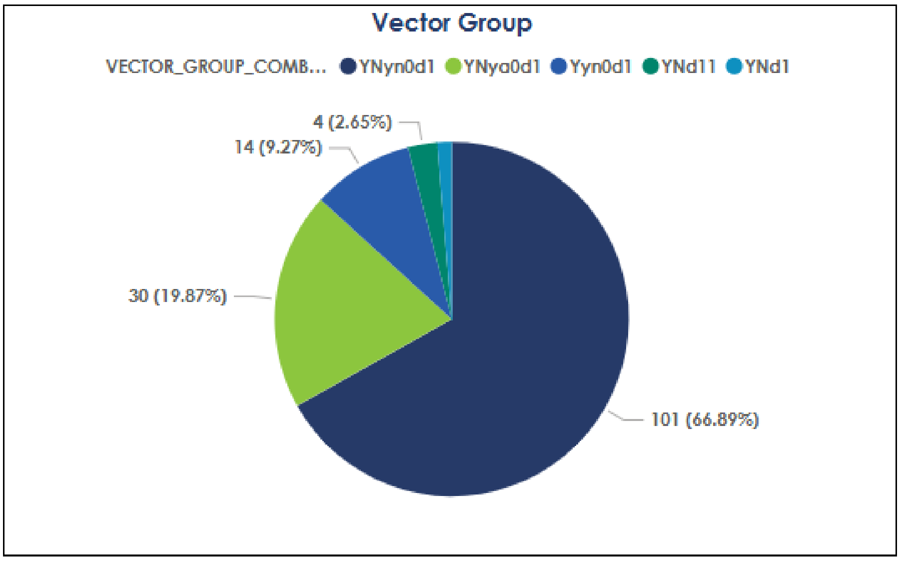


Figure 6: Percentage of Total Transformer Fleet by Vector Group

3.2.5. Spares

The power transformer inventory comprises both strategic and emergency spares. Strategic spares are engineered for universal compatibility across voltage levels and vector configurations. Upon deployment, these units typically serve as permanent replacements unless significantly over-specified, in which case they may be reassigned as spares if economically viable. The following table details the strategic spare transformers.

STATION	TRANSFORMER NAME	PRIMARY VOLTAGE	NOMINAL RATING (MVA)	MANUFACTURER	AGE	VECTOR GROUP
WOTS	Spare X	330	75	[C.I.C]	3	YNyn0d1
MLTS	SPARE A	500	333	[C.I.C]	20	Ia0i1
HWTS	SPARE A	500	200	[C.I.C]	57	Ia0i1
KTS	SPARE A	500	250	[C.I.C]	54	Ia0i1
KTS	SPARE COUNTRY	220	150	[C.I.C]	7	YNyn0d1
SMTS	SPARE COUNTRY	220	150	[C.I.C]	8	YNyn0d1
SMTS	SPARE F	500	333	[C.I.C]	43	Ia0i1
SMTS	SPARE F	500	333	[C.I.C]	2	Ia0i1
HTS	SPARE METRO	220	150	[C.I.C]	7	YNyn0d1
TTS	SPARE METRO	220	150	[C.I.C]	7	YNynd01
BLTS	SPARE U	66	60	[C.I.C]	19	YNyn0d1

Table 1: Strategic Spare Transformers

Emergency spares are intended to be used to temporarily provide service in the event of a failure, until a permanent replacement is implemented. They consist of:

- Mix of retired and strategic transformers to operate as in-service Hot Spares providing in-service operation flexibility at the connection node. These are listed in Table 2.
- Retired transformers that remain onsite in a disposed or out-of-service state and are not subject to ongoing maintenance represent a tactical solution for emergency transformer salvage. This category is considered a tertiary level of spare support, and these units are excluded from the regulated asset base (RAB). Relevant details can be found in Table 3.

STATION	TRANSFORMER NAME	PRIMARY VOLTAGE	NOMINAL RATING (MVA)	MANUFACTURER	AGE	VECTOR GROUP
SMTS	H2 R ph- HOT SPARE	330	233	[C.I.C]	57	YNyn0d1
SMTS	H2 W ph - HOT SPARE	330	233	[C.I.C]	57	YNyn0d1
SMTS	H2 B ph- HOT SPARE	330	233	[C.I.C]	57	YNyn0d1
MBTS	B1 - HOT SPARE	220	50	[C.I.C]	20	YNyn0d1

Table 2: Hot Spares (In Service)

STATION	TRANSFORMER NAME	PRIMARY VOLTAGE	NOMINAL RATING (MVA)	MANUFACTURER	AGE	VECTOR GROUP
MWTS	Ex B2	220	165	[C.I.C]	54	YNyn0
BLTS	Ex B4	220	150	[C.I.C]	58	YNyn0d1
DDTS	Ex H1 R ph	330	75	[C.I.C]	66	Ia0i1
DDTS	Ex H1 W ph	330	75	[C.I.C]	66	Ia0i1
DDTS	Ex H1 B ph	330	75	[C.I.C]	66	Ia0i1
DDTS	Ex H2 W ph	330	75	[C.I.C]	66	Ia0i1
DDTS	Ex H2 B ph	330	75	[C.I.C]	66	Ia0i1

Table 3: Emergency Spares (Disposed)

The spare transformer inventory is configured to provide coverage for 92% of in-service units. Notable exclusions are:

- SVC transformers at ROTS, HOTS, KGTS
- 500/275kV M transformers at HYTS
- 500/220kV three phase A transformer at HWTS
- 220/66kV 225MVA high impedance B transformer

The asset consequence of failure to date has not driven a spares strategy for the SVC transformers.

There are no specific spares for the 500/275kV M transformers at HYTS and the three phase A transformer at HWTS. There is however enough redundancy to sustain the failure of a single transformer for the short term.

Currently, there is no dedicated spare unit available for the 220/66kV 225MVA high impedance B transformer. In the event of a failure, existing 150MVA metro spare units may be deployed as a temporary contingency. However, due to impedance mismatch between the 150MVA and 225MVA units, parallel operation would result in poor load sharing and a reduction in station output capacity.

With 13 units of 225MVA B transformers already commissioned across the network and further installations planned, the cumulative energy-at-risk continues to grow. There is currently a case for a dedicated spare unit due to load at risk at SMTS, however AusNet's Distribution Business has a RIT-T underway to address this risk and so a spare has not been proposed at this stage.

4. Asset Performance

In power transformer asset management, performance assessment is key to effective lifecycle management. Performance data helps identify trends and patterns in asset behaviour, which are crucial for making strategic decisions regarding maintenance, upgrades, and replacements. 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 health and reliability of the assets.

The following section will discuss "ZA and ZK notifications". It is important to note AusNet uses notification analytics to support its health score and Weibull models for asset risk assessment.

4.1. Defect Analysis

Figure 7 below, shows ZA (condition-based corrective maintenance) and ZK (failure) notifications for power transformers per financial year. There have been on average 338 notifications annually over the last five years.

Based on the notification data from 2020 to mid-2025 for power transformers, there have been notable step changes in the notification numbers due to the limited accessibility to the assets for planned routine maintenance and rectifications during the COVID statewide lockdown in 2020 and early 2021, resulting in more rectifications required after the lockdown was lifted.

The 220 kV voltage level consistently accounted for the highest number of notifications each year due to the 220kV connection transformer being more widely deployed.

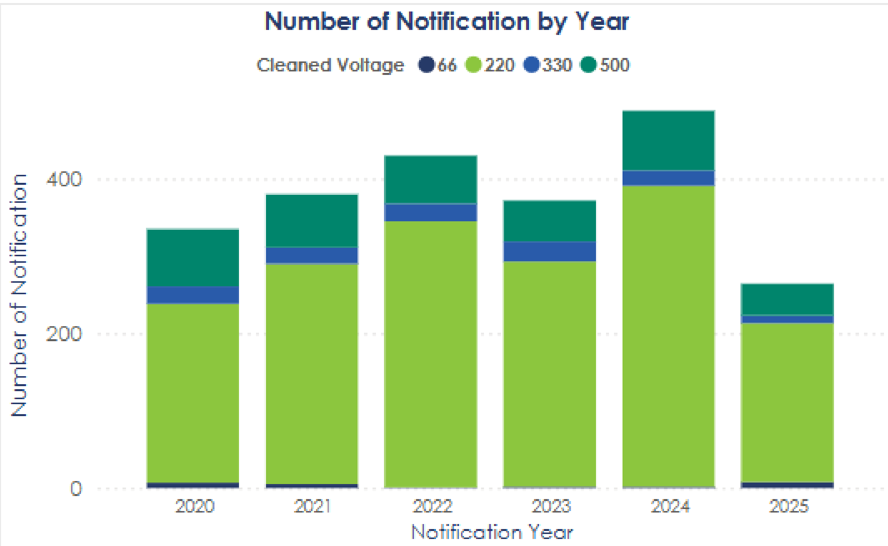


Figure 7: ZA and ZK Notifications per Financial Year and Voltage

Figure 8 presents the Top 10 Notifications from 2020 to mid-2025, categorised by voltage level and notification object type. The distribution of failure notifications across voltage classes highlights component-specific performance concerns within the transformer asset group. Notably, 220 kV transformers continue to generate the highest volume of notifications, particularly related to cooling and auxiliary components such as fans, pumps, transformer management system, conservator bags, dehydrating breathers, control circuitry, and electrical wiring. 330 kV and 500 kV transformers also show moderate notification volumes, with recurring issues in fans, pumps and TMS. These trends suggest potential thermal performance degradation across all voltage classes and may indicate that these systems are approaching the end of their design life. The failure issues with Transformer Management System (TMS) are notable and a replacement program is proposed for obsolete types for 2027-32.

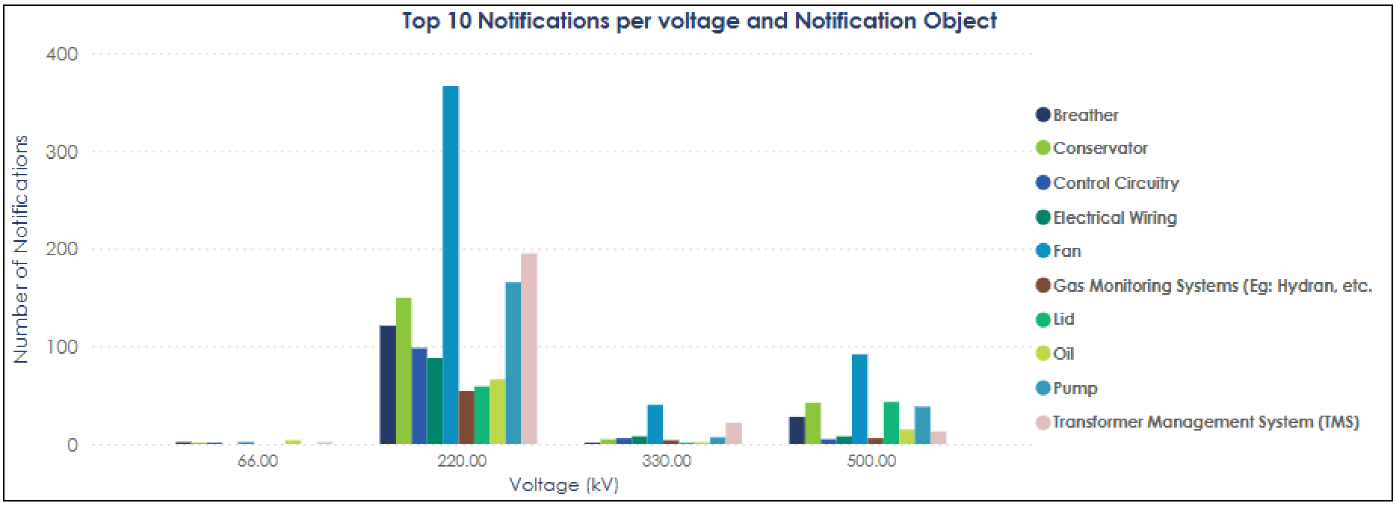


Figure 8: Top 10 Notifications 2020 - mid 2025 per Voltage and Notification Object Type

4.2. Major Failures

During the current regulatory period (2020–mid 2025), no major failures were recorded for transformers and reactors within this asset class. This reflects the effectiveness of existing asset management practices, including condition monitoring, maintenance strategies, and risk-based investment planning and replacement. The absence of major failures has contributed to sustained network reliability and safety performance over the period. The historic major asset failure record is shown in Appendix 1.

5. Asset Health

The asset's health condition is represented by the likelihood of failure profile, which is derived from condition monitoring data and detailed in Section 4, Asset Performance, of this document, particularly within the performance analysis subsection. The following graphs illustrate the likelihood of failure profiles from multiple perspectives, including object type, voltage level, and asset age, and the likelihood score reflects the probability of failure, with 1 being the least likely and 5 being the most (Refer to the table below and AMS 01-09. By examining these dimensions, we can obtain a comprehensive view of the asset health condition and the associated program of work proposed.

LIKELIHOOD BUCKET	LIKELIHOOD SCALE
5	Very Likely
4	Likely
3	Possible
2	Unlikely
1	Very Unlikely

Table 4: Likelihood Scale

5.1. Power Transformer

Figure 9 "Asset Likelihood by Voltage" below provides a clear view of the distribution of failure likelihood across the transformer fleet. Approximately 60% of transformers have a Likelihood Score of 1 or 2, which corresponds to a low probability of failure. Most of these transformers operate at 220 kV. As the likelihood score increases (from 3 to 4), the distribution of assets becomes more evenly spread across voltage levels, including 220 kV, 330 kV, and 500 kV. Notably, several 330 kV and 500 kV shared network transformers located at SMTS, KTS, and DDTS exhibit a high failure likelihood with a Score of 4.

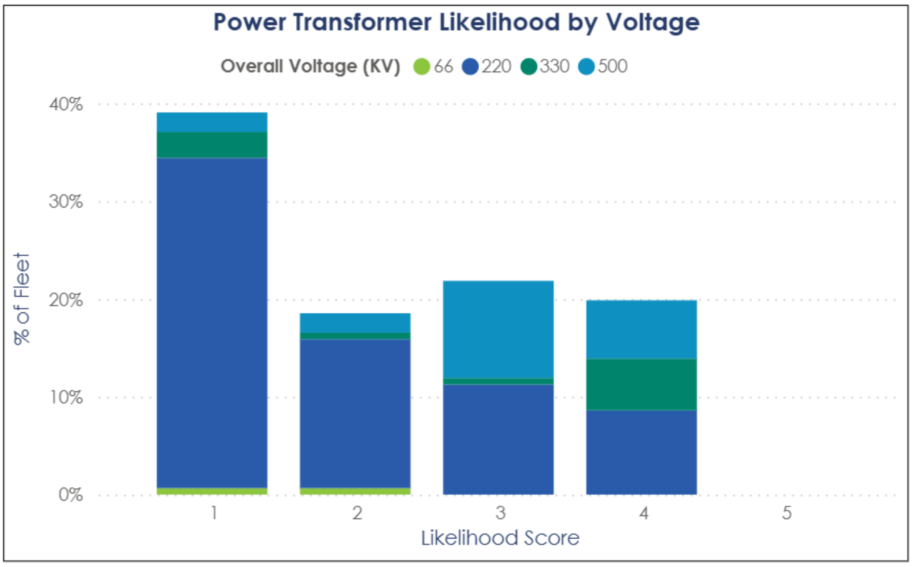


Figure 9: Transformer Overall Likelihood score per Voltage

Figure 10 presents asset likelihood aligned with transformer age, offering a clear view of how failure risk evolves over time. Most transformers aged below 30 years fall into Likelihood Bucket 1 & 2, indicating low risk. However, as assets get above 30 years, the distribution spreads across higher likelihood buckets, reflecting increased risk. Notably, transformers aged 50 years and older show a sharp rise in higher likelihood scores, indicating some correlation between age related deterioration mechanisms and failure probability due to the material aging behaviour.

The refurbishment program can be leveraged to replace critical components such as bushings, winding temperature indicators (WTI), and transformer management system (TMS), thereby extending the operational lifespan of the transformer. However, there are no viable refurbishment options for the windings and core, which are key determinants of end-of-life and will ultimately necessitate full transformer replacement.

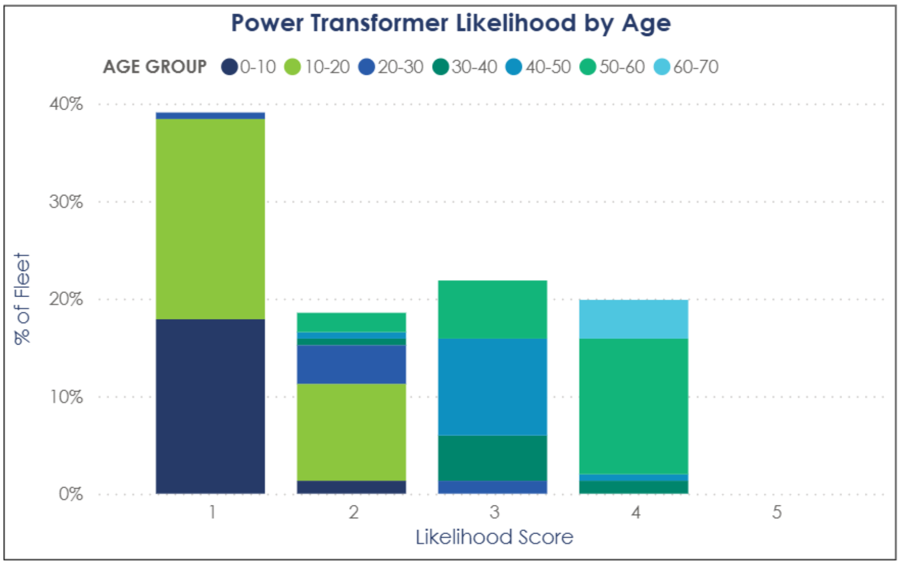


Figure 10: Transformer likelihood against age

5.2. Oil Filled Reactors

Figure 11 "Likelihood by Voltage" presents the distribution of oil-filled reactor assets across likelihood scores and voltage levels. The majority of the fleet with a Likelihood Score of 1 and 2 operates at 66kV and 220 kV, representing approximately 60% of the total population, show a low probability of failure for this group. Notably, 500 kV reactors appear predominantly in Likelihood Score 4, suggesting a higher risk profile for these high-voltage units.

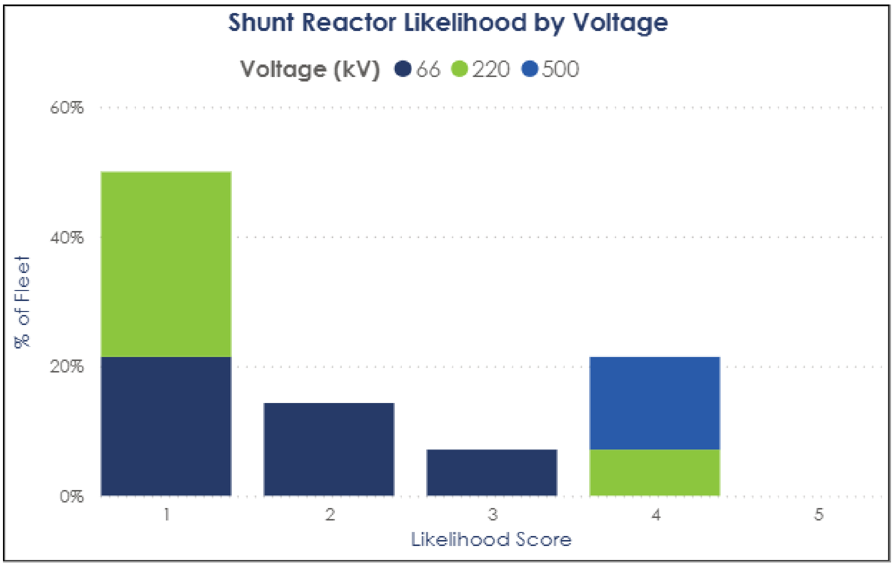


Figure 11: Oil Filled Reactor Overall Condition Score per Voltage

Figure 12 shows how the likelihood of failure for oil-filled reactors increases with age. For units under the age of 10, all assets are classified within Likelihood Bucket 1, denoting low risk. By ages 20 to 30, asset distribution transitions toward Buckets 2 and 3, which correspond to a moderate risk profile. For units over 40 years, the entire population is in Bucket 4, highlighting a high probability of failure and the need for targeted intervention or replacement planning. The aging 220kV and 500kV shunt reactors, mainly at MLTS to provide over-voltage control at the terminal station and on the long transmission lines, are exhibiting end-of-life conditions, with a significantly increased risk of failure.

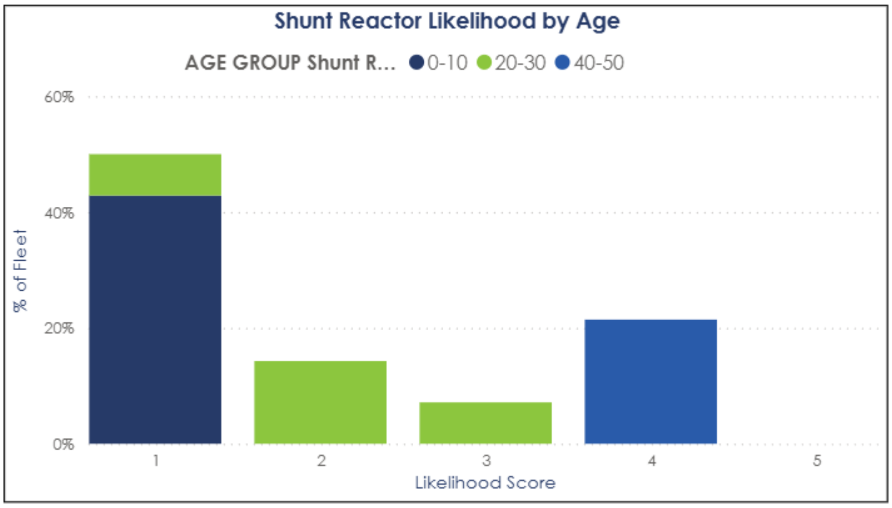


Figure 12: Oil Filled Reactors Likelihood by Age

5.3. Components

5.3.1. Power Transformer and Shunt Reactor Bushing

As of September 2025, AusNet's fleet of power transformers and shunt reactors comprises a total of 1209 bushings across all voltage classes. EHV/HV bushing technologies used in AusNet's power transformers vary based on the transformer's vintage, design specifications, operating environment, and the bushing technologies deemed acceptable at the time of manufacture. Periodic offline condition monitoring and visual inspections are conducted to evaluate both the electrical and mechanical integrity of the bushings. Bushings exhibiting signs of deterioration or poor condition are subject to close monitoring and scheduled replacement to mitigate the risk of catastrophic failure.

Figures 13 to 15 indicate that multiple oil-impregnated paper (OIP) and Synthetic Resin Bonded Paper (SRBP) bushings across voltage levels, 500kV, 330/275kV, 220kV, and 66kV, are exhibiting signs of advanced insulation deterioration, resulting in a likelihood score of 4. The three primary contributing factors are moisture ingress, oil degradation, and paper aging. Notably, some bushings proposed for replacement have a likelihood score of 3; however, they are being considered for replacement to optimise maintenance efficiency and cost. Replacing these bushings while the transformer is already drained allows for the generation of additional spares, making the overall process more economical.

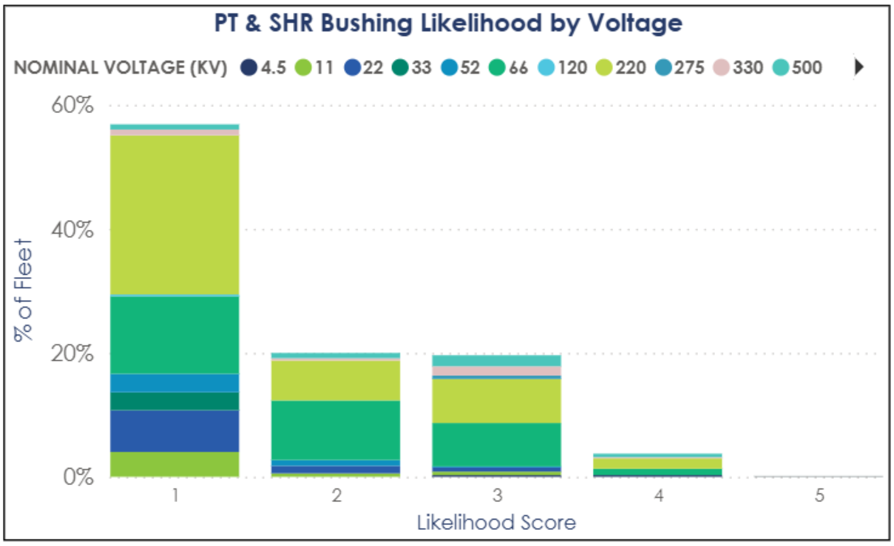


Figure 13: PT & SHR Bushing Likelihood score per Voltage

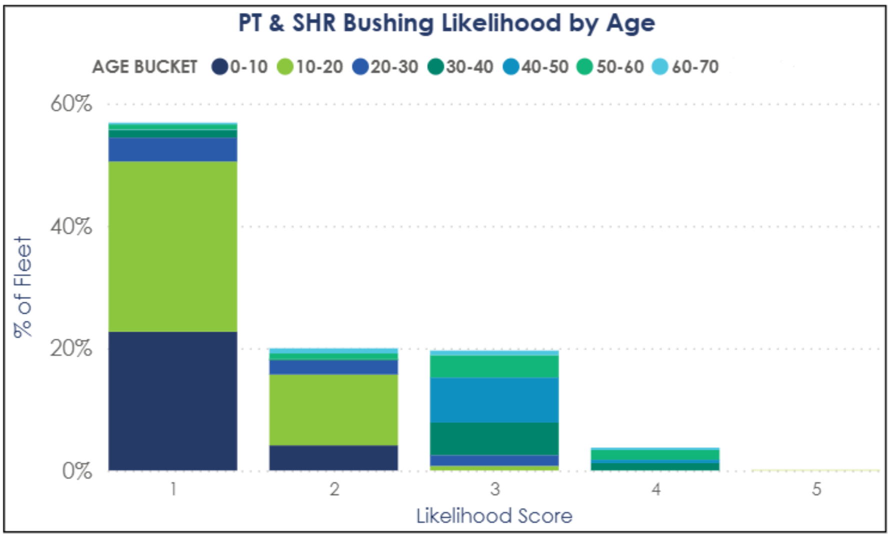


Figure 14: PT & SHR Bushing likelihood against age

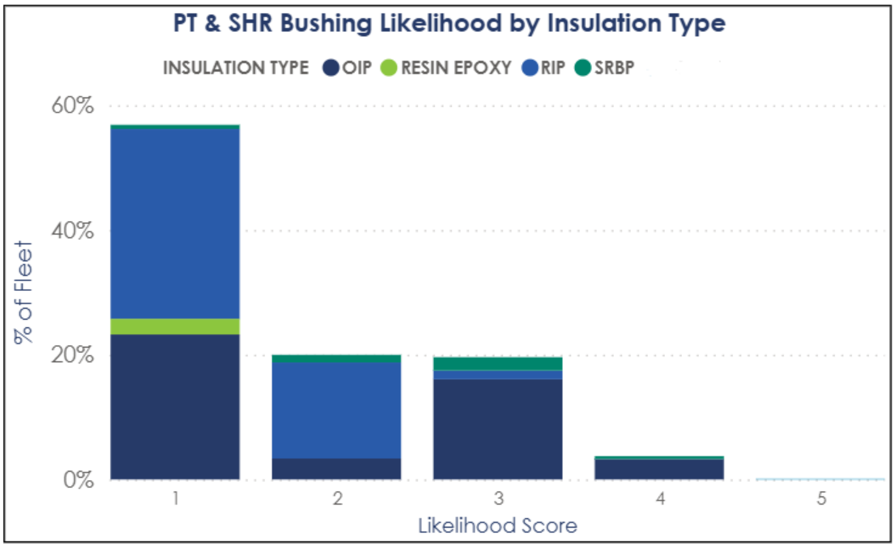


Figure 15: PT & SHR Bushing likelihood against insulation type

The following bushing models have been identified with advanced deterioration, resulting in high failure risks if they are not managed. Therefore, a program of work for bushing replacement has been proposed in the 27-32 TRR that's addresses likelihood score 4 bushings, not being addressed as wholesale transformer replacement. These types are described below. Refer to Section 7.4. Proposed Program for the detailed program.

[C.I.C]/ [C.I.C] 220kV and 66kV OIP Bushings

The 220kV and 66kV [C.I.C]/[C.I.C] OIP bushings installed during the 1970s–1980s are exhibiting signs of advanced internal oil degradation, with some instances of oil seal failure also noted. In 2023, the final direct replacement spare 220kV [C.I.C] bushing was installed at BETS, highlighting the urgent need to identify and procure suitable alternative adapted spare bushings. This should serve as a precursor to a broader fleet replacement strategy.

Replacement of the 220kV [C.I.C] OIP bushings at HWTS A2, A3, and A4 has already been scheduled within the current TRR period. To mitigate the risk of catastrophic failure, it is recommended that the replacement program be extended to the remaining [C.I.C] fleet during TRR periods 27–32.

[C.I.C] 500kV, 330/275kV and 220kV OIP Bushings

The [C.I.C] bushing fleet across 500kV, 330/275kV, and 220kV voltage levels, primarily manufactured in the 1970s–1980s, with a small subset dating back to the 1960s, is exhibiting signs of degradation due to the impact of 100 Hz vibration on critical oil seals. This deterioration poses a risk of uncontrolled insulating oil loss, which can lead to explosive bushing failure once the internal paper insulation is exposed. Such failures can result in widespread porcelain fragmentation, endangering nearby equipment and personnel.

The older vintage [C.I.C]/[C.I.C] bushings from the 1960s have already been replaced during the current TRR period, including the 500kV and 220kV OIP bushings at KTS A2, A3 and A4. As part of the 2027–2032 TRR reset period, it is recommended that the remaining in-service EHV [C.I.C] bushings be replaced with suitably designed modern RIP/RIS bushings to continue the fleet refurbishment program.

5.3.2. Winding Temperature Indicator and Cooling Control

The winding temperature indicator (WTI) is a temperature monitoring and cooling control device for old vintage transformers, with design life beyond 45 years. Beyond this period, its reliability declines significantly, potentially leading to inaccurate thermal cooling control and compromised temperature monitoring performance.

There are 174 sets of WTIs installed across the network, with each transformer tank fitted with one set, comprising one unit for the HV winding and one for the LV winding. Of these, 18 sets are either approaching end-of-life or are faulty and require replacement.

The WTI that is faulty or incorrectly calibrated, may cause the transformers to be incorrectly loaded. In the worst case, unknowingly overloading transformers will lead to early replacement or failure. To mitigate the associated risks, AusNet has progressively replaced end-of-life WTI units across multiple TRR periods. Continuing this replacement program in TRR 27–32 is therefore a critical step in maintaining network reliability and asset performance.

5.3.3. Transformer Management System (TMS)

The transformer management system is a smart device which has various monitoring and control capabilities to perform smart temperature monitoring (including fiber optic hot spot temperature monitoring) and dynamic cooling control to the power transformer, and it has a design life of around 20 years due to the main components are electronic devices. For the modern transformer fleet, TMS is installed to perform cooling control instead of WTI.

There are 103 TMS units installed across the network, with each transformer tank fitted with one unit. Of these, 43 units are approaching end-of-life and are no longer supported by the original manufacturer. The obsolete models include DRMCC T1, T2, and T3, as well as the [C.I.C] TIC model.

The legacy TMS units have reached end-of-life and are no longer supported by the original manufacturer due to obsolescence. Any failure of these obsolete devices may lead to inefficient cooling control and potentially cause transformer overloading without timely detection. TMS failures are the second most frequent occurrence on the defect/notification analysis. To mitigate these risks, a replacement program is proposed to systematically replace 25 units out of the 43 faulty or obsolete TMS units, covering each obsolete type. The program also aims to increase spare inventory to support the remaining in-service vintage models.

5.3.4. Phase Isolated Bus (PIB)

PIBs (Phase Isolated Buses) are installed on the A transformers at HWTS and KTS, SMTS F2 and MLTS A1. Each of the PIB are different designs, and the PIBs on the A2, A3, and A4 single phase transformers at HWTS are in poor condition due to water leaks and corrosion issues. Water leaks will eventually lead to an earth short that's causes a winding failure in one of the phases. Although HWPS has closed, the transformers are still critical assets for the renewable connections in the La Trobe Valley and damage to an A transformer phase will result in energy constraint for a period of at least 6 weeks.

Deterioration PIBs at HWTS is exacerbated in comparison to other installations as their construction contains many vertical intersection expansion joints. This allows elevated rate of moisture ingress. A trial program will be conducted on one phase during the current TRR period to address the leak issue and validate the refurbishment concept. Subject to successful outcomes, a full refurbishment program will be implemented in TRR 27–32 to complete the rectification across all affected phases.

6. Related Matters

The following sections summarise the major issues that require remediation actions within this strategy document, individual replacement program and the corrosive sulphur plan. More details and specific issues are included in the transformer asset health report AHR 10-141.

6.1. Core, Winding and Tank

6.1.1. Moisture Content

Moisture reduces dielectric strength of oil-paper insulation, which can lead to the inception of partial discharges or dielectric thermal runaway at elevated ambient temperatures. The degradation is pronounced with increased load and moisture levels of greater than 4%.

Free-breathing transformers installed prior to 1978 are exhibiting elevated levels of moisture.

The H1 and H2 transformer banks at South Morang terminal station (SMTS) are exhibiting high transformer oil and insulation moisture level. A project is currently underway to replace these transformers.

6.1.2. Corrosive Sulphur

Between 1999 and 2006, oil supplied by a major vendor may have contained corrosive sulphur. This contaminant can cause premature deterioration of copper windings and OLTC selector silver contacts. Testing conducted on 66 transmission transformers potentially affected by this issue revealed the presence of corrosive sulphur in 72% of cases.

Oil passivators are effective against copper degradation, but recent findings show that corrosive sulphur still corrodes OLTC selector silver contacts. Processing the oil is the only solution for silver tinned contact degradation. AusNet has purchased an oil regeneration plant, and an oil regeneration OPEX program is underway, scheduled for completion in the next TRR 27-32 period.

6.1.3. Paper Insulation Deterioration

Deterioration of paper winding insulation is influenced by temperature, moisture, oxygen, and certain byproducts of oil oxidation. When the degree of polymerisation (DP) of paper insulation drops below 200, the mechanical strength of the winding is reduced, making it unable to withstand through faults according to its original specification. This condition is not reversible for a transformer. Continuing to operate a transformer under these circumstances is determined by the likelihood that a significant through fault will not occur. Estimated DP values from KTS A4 and MLTS No.2 500kV Shunt Reactors indicate that the paper insulation has reached the end of its operational life. These assets will be replaced under our proposed program.

6.1.4. Short Circuit Strength of Transformers

Thermal aging of transformers insulation leads to mechanical weakening of the insulation structure and increased risk of damage due to the sudden electromagnetic forces created by short circuit through currents.

Initial transformer design calculations, conducted prior to the implementation of computer-aided design, have proven inadequate when compared to contemporary assessment techniques. [C.I.C], [C.I.C], and [C.I.C] 'B' transformers installed during the 1960s to 1980s in high-load stations are particularly vulnerable. The vulnerable units are being progressively replaced over multiple TRR periods, including TTS B4 and BATS B2, as part of our proposed program.

6.2. On Load Tap Changers (OLTCs)

6.2.1. Oil vs Vacuum Maintenance Needs

Oil type On Load Tap Changers (OLTCs) are known for being maintenance intensive. If these devices are not properly maintained, they can ultimately cause transformer failure, effectively ending the operational life of the transformer. A particular challenge arises with [C.I.C] OLTCs, as their maintenance often requires assistance from the manufacturer, further increasing the cost and complexity of upkeep.

[C.I.C] Class M and [C.I.C] UC oil-filled OLTCs, which were installed during the 1990s and early 2000s, can be retrofitted with vacuum OLTCs. This retrofit offers significant advantages in terms of maintenance. Vacuum OLTCs are capable of performing up to 600,000 operations before requiring invasive maintenance. In comparison, oil OLTCs typically require maintenance every four years, making vacuum OLTCs a low-maintenance alternative that may not need invasive intervention for the entire operational life of a transformer.

Replacing oil-filled OLTCs with vacuum OLTCs therefore presents a compelling case for reducing maintenance demands. Vacuum OLTCs require minimal ongoing maintenance and offer increased longevity, addressing many of the issues associated with traditional oil-based OLTCs.

6.3. Bushings

6.3.1. Maintenance and Online Monitoring

The condition of bushings is currently determined by offline electrical tests and oil sampling. Due to generation and interconnection constraints, transformers on the shared network are becoming increasing difficult to take offline for testing. However, the safety consequences of a failure mean the condition still needs to be determined. One solution is to install on-line monitors on 'market' critical transformer that trigger inspection or replacement once acceptable threshold is breached. Currently there is only one bushing monitoring system installed on the shared network transformer bank as a trial at SMTS. Based on the current trial experience, the existing brand has not performed as expected, and alternative online monitoring solutions will be explored moving forward.

6.4. Protection, Control and Auxiliary Components

6.4.1. Secondary: Protection, Control and Monitoring Wiring

The secondary wiring insulation can deteriorate over time and fault to a short circuit or open circuit. The deterioration is generally due to exposure from UV, tank heat, mechanical damage and insulating oil ingress. Once identified, the cabling will need to be replaced, to maintain the required transformer performance and safe operation.

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 power transformers and oil filled reactors, risk treatment required to achieve this over time involves replacement & maintenance activities. Justification for these projects are developed based on current risk 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 conditional Probability of Failure (PoF) for power transformers, oil-filled reactors, and their bushings is assessed using a health score-based methodology. Despite the relatively small asset population, the availability of extensive historical data (particularly from insulating oil chemical analyses and high-voltage electrical testing) enables robust and accurate health score calculations.

Each measurement provides a Health Index (HI) rating from 1 to 5, where 1 indicates optimal health and 5 indicates worst health. These failure modes are based on diagnostic criteria derived from IEC and IEEE guidelines, CIGRE Technical Brochure 761 (Condition Assessment of Power Transformers), the Transformer Fleet's Asset Health Report (AHR 10-141), and the collective expertise of industry subject matter experts. For each failure mode, the highest (i.e., worst) Health Index is selected and used as input for calculating the overall health score or the Transformer Assessment Index (TAI), which supports replacement or refurbishment decisions. This process aligns broadly with the methodology outlined in CIGRE TB 761.

Once health scores are established, Weibull statistical models are applied to project PoF values across future years. This approach aligns with the calculation methods outlined in AMS-01-09, which emphasizes the use of health scores due to the rich dataset available for these assets.

The oil and electrical test results, along with physical inspection findings, provide insights into the condition of key failure modes, as summarised in the table below.

FAILURE MODE	CONDITION/ISSUES
Thermal	• Overheating of conductors and joints • Accelerated ageing of insulation materials • Issues with core insulation and internal metal structures
Winding & Core Dielectric	• Deterioration of solid insulation leading to breakdown • Contamination of insulating oil leading to dielectric failure of windings • Physical or chemical contamination • Corrosive Sulphur issues in copper windings (1990–2006 vintage): Mitigated through passivation — *effectiveness*
Mechanical	• Changes in winding geometry reducing fault tolerance • Deterioration of tank or cooling system structures or sealing

Insulating Oil	• Contamination leading to insulation failure • Poor oil flow causing faster paper ageing
OLTC	• Wear and tear of drive components and contacts • Degradation of insulation materials • Corrosive Sulphur issues affecting silver contacts (1990–2006 vintage): mitigated through oil regeneration — *effectiveness*
Bushing	• Physical and electrical degradation • Seal and weather shield issues (non-graded types) • Physical seals and dielectric failures in condenser-graded types (OIP, SRBP, RIP, RIS – with porcelain or Si-polymer weather shield)
Secondary Systems	• Wiring and component ageing causing failures or incorrect operation

Table 5: Failure mode against associated condition/issues

For WTIs and TMS replacement a different approach is required. By replacing unreliable and obsolete components such as WTIs or TMS units, transformers can be operated confidently to their full expected life, as the risk of unintentionally overheating resulting in accelerating aging or more extreme thermal runaway failure remains low. The value of this upgrade is reflected in a reduced Probability of Failure (POF), which is treated as equivalent to a one year extension in the transformer life.

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 key lenses: Safety, Environment, Customer/Market Impact and Financial consequences. These lenses provide a structured view of the potential impacts, resulting in loss of energy supply, injury to employees or members of the public, or environmental hazards. Table 6 summarises the focus of each lens:

CONSEQUENCE LENSES	DESCRIPTION
Safety	Threat to health and safety of people
Environment	Fire/smoke damage Oil Spills
Customer / Market	Loss of Supply to Customers Impact on energy market
Financial	Asset/Component replacement costs Collateral damage Emergency response repairs/replacements

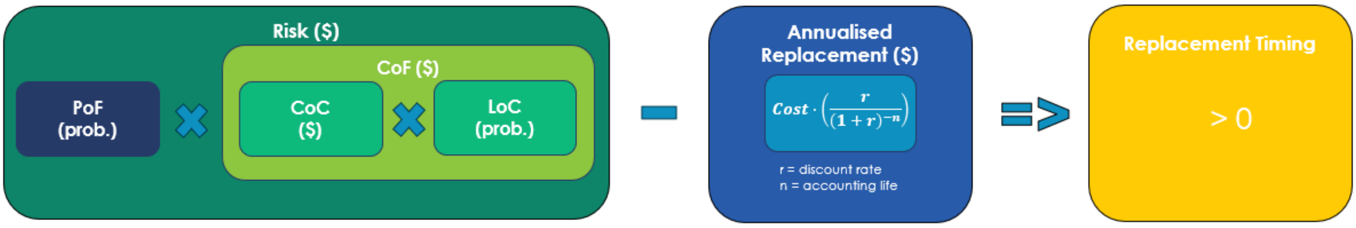
Table 6: Consequence lens description

7.2. Economic Viability

7.2.1. Economic Model

Asset Management 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 shown visually in Figure 9 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 2027-32 Asset Replacement Economic Model – Power Transformers and Oil Filled Reactor Component Replacements – Final



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 support the interpretation of model outputs in the context of engineering interventions, operational insights, and current asset condition.

Assessments as to whether the asset replacement or refurbishment or change in maintenance regime or no action are reasonably practicable choices. This involves verifying condition data, evaluating operational priorities, and considering strategic timing of interventions. Where appropriate, recommendations may provide alternative actions based on their professional assessment.

This validation process complements the use of 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

Detailed replacement programs for wholesale power transformer and shunt reactor replacement and components replacement are proposed for the TRR 27–32 regulatory period. Wholesale replacement is delivered through the Major Station Projects program. These programs are comprehensively outlined in the Major Project Planning Reports and Condition Reports.

The component replacement proposed works specifically target known issues with power transformers and shunt reactors, including Deteriorated bushings, Faulty Winding Temperature Indicators (WTIs), Obsolete and unreliable electronic Transformer Management Systems (TMS), and deteriorated sealing on outdoor Phase Isolated Bus (PIB) systems. These initiatives are designed to reduce failure risk and extend asset life, thereby deferring full transformer or reactor replacement. The detailed component replacement program is provided in Table 7 below. This program builds on previous TRR initiatives focused on bushing, WTI, and TMS replacements, and reflects a prudent lifecycle management approach for critical station assets.

AusNet will also continue its proactive oil regeneration program under OPEX, targeting transformers affected by corrosive sulphur in oil. This condition accelerates degradation of copper windings and OLTC selector silver contacts. The program is currently underway and is expected to be completed during the TRR 27–32 period.

COMPONENT TYPE	POWER TRANSFORMER COMPONENT DESCRIPTION	QUANTITY
PIB	PIB Refurbishment - HWTS A2, A3 & A4	3 (bank)
WTI	Winding Temperature Indicator (WTI) Replacement (Refer to ANT – TRR 2027-32 Asset Replacement Economic Model – Power Transformers and Oil Filled Reactor Component Replacements – Final for the full list)	18 (tank)
TMS	Transformer Management System (TMS) Replacement (Refer to ANT – TRR 2027-32 Asset Replacement Economic Model – Power Transformers and Oil Filled Reactor Component Replacements – Final for the full list)	23 (tank)
Bushing	**500kV [C.I.C] OIP Bushing Replacement** (HYTS M2, MLTS No.1 500kV Shunt Reactor, HWTS A1)	3 (tank)
	330/275kV [C.I.C] OIP Bushing Replacement (HYTS M2, DDTS H3)	2 (tank)
	220kV [C.I.C] OIP Bushing Replacement (HWTS A1, TBTS B1 & B2, FBTS B3, MWTS B3, BETS B4, ATS B2, KGTS B2 & B3)	9 (tank)
	66kV [C.I.C] OIP Bushing Replacement (TBTS B1 & B2, FBTS B3, RWTS B3, MWTS B3, BETS B4, WOTS X1 & X2, KGTS B2 & B3)	10 (tank)
	SRBP Neutral Bushing Replacement (HYTS M2)	1 (tank)

Table 7: Proposed Program

8. Asset Strategies

The following section summarises the strategies. The itemised program of work for transformer components is presented in Section 7.4. Proposed Program.

8.1. New Installations

- Continue to invest in specification and manufacturing quality assurance to continue to minimise early life issues or random midlife failures.

8.2. Condition Monitoring

- Continue evaluating the performance and reliability of the installed online bushing monitoring system and assess the feasibility of extending its application to other critical transformers to enhance asset condition monitoring and risk mitigation.
- Continue periodic offline HV condition monitoring tests. Continue to assess all the current and historic condition data with industry best practise in analysis techniques, to determine individual components suitability for continuing service or need for plan refurbishment or replacement. Also, where relevant for components, determine fleet performance and need for refurbishment or replacement as a fleet consideration.
- Inspect and evaluate bushings exhibiting poor mechanical condition.
- Develop a predictive bushing model to forecast potential accelerated deterioration between offline condition monitoring intervals. Adjust the monitoring frequency as needed to support timely detection and mitigation of emerging risks.
- Continue to develop transformer data analysis capability utilising the Information Management platform to optimise maintenance and replacement programs.

8.3. Maintenance

- Continue scheduled preventative maintenance as per specific standard maintenance instructions.
- Continue to update/create measurement points in SAP to capture condition information.
- Continue to update maintenance instructions and plans as new deterioration trends become apparent.

8.4. Spares Holding

- Continue to maintain spare transformers at strategic network locations in accordance with transformer spares holding policies. Additionally, Facilitate the availability of critical spare components such as bushings, OLTC diverter switches, and transformer management system (TMS).

8.5. Refurbishment

- Continue to address risk of diverter switch deterioration due to oil contaminated with corrosive sulphur.

- Refurbish the Phase Isolated Bus (PIB) systems for HWTS A2, A3, and A4 transformers to eliminate water ingress and restore insulation integrity, thereby mitigating the risk of phase-to-ground faults and preventing potential catastrophic failure due to the deteriorated condition of the PIB
- When required to reclaim the insulating oil to maintain an acceptable service risk.

8.6. Replacement

- Continue risk based transformer replacement based on the core and winding intrinsic end of life condition score and transformer asset criticality – specific proposals are outside the scope of this document.
- Replace Identified advance deteriorated OIP and SRBP bushings where possible with RIP /polymer technology
- Replace deteriorated and faulty WTIs and obsolete Transformer Management System (TMS) to deliver correct transformer cooling management and avoid over temperature condition.
- When identified replace degraded secondary cable

9. Resource references

No.	TITLE
1	AMS 01-05 Strategic Asset Management Plan
2	AMS 01-09 Asset Risk Assessment Overview
3	ANT – TRR 2027-32 Asset Replacement Economic Model – Power Transformers and Oil Filled Reactor Component Replacements – Final

10. Schedule of Revisions

ISSUE NUMBER	DATE	DESCRIPTION	AUTHOR	APPROVED BY
5	06/11/2006	Editorial review	[C.I.C] [C.I.C]	[C.I.C]
6	15/02/2007	Review and Update	[C.I.C] [C.I.C]	[C.I.C]
7	17/03/2007	Editorial Review	[C.I.C] [C.I.C]	[C.I.C]
8	17/04/2007	Update of failure rates	[C.I.C]	[C.I.C]
8.1	01/08/2011	Revised Structure & General Update	[C.I.C]	
9	07/01/2013	Review, Update and Revised Structure	[C.I.C] [C.I.C]	[C.I.C]
10	28/08/2015	Review and Update (Regulated Assets Only)	[C.I.C] [C.I.C] [C.I.C]	[C.I.C]
11	16/07/2020	Review and Update	[C.I.C]	[C.I.C]
12	30/08/2025	Review and update	[C.I.C] [C.I.C] [C.I.C] [C.I.C] [C.I.C]	[C.I.C]

Contact

This document is the responsibility of Transmission - Network Management Division of AusNet. Please contact the indicated owner of the document with any inquiries.

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

Appendices

Appendix 1 – Major Failures

STATION	TRANSFORMER	MANUFACTURER	FAILURE DATE	AGE AT FAILURE	NATURE OF FAILURE	EXTENT OF DAMAGE	REMEDIAL ACTION
TTS	B3	[C.I.C]	8/09/1978	11	Tap changer operated beyond end tap resulting in a tap change from tap 1 to tap 10 – flashover in diverter switch.	Failed tapping windings, 66 kV windings and tertiary on two phases, tertiary on one phase faulted to core – fault current extensively through core – core had to be complexly dismantled.	Transformer repaired at a high cost.
DDTS	H1 W ph.	[C.I.C]	31/12/1986	27	220 kV bushing failed resulting in a fire.	This is a shell type design – Windings completely burnt out, foundations damaged, connecting busbars & conductors damaged, adjacent Surge arresters and one bushing damaged, cubicles burnt.	Transformer repaired using spare winding. Foundation, etc was rebuilt.
SVTS	B3	[C.I.C]	6/04/1995	35	Inter-strand fault in "b" phase 66 kV winding resulted in gassing when on load. No other damage	Conductor insulation burnt at site of failure at a transposition point.	Transformer repaired at a cost of [C.I.C] using a spare winding to affect a quick return to site. Then later repaired the failed removed winding.

MTS	L2 W ph.	[C.I.C]	April 95	26	Winding failure following external short circuit – LV and tertiary winding damage (in hindsight we believe some movement occurred during a similar fault about 15 years earlier	LV and tertiary winding damaged and had to be replaced	Transformer repaired at a cost of [C.I.C]
BATS	B1	[C.I.C]	12/12/2000	30	Open circuit developed on one connection in the diverter switch resulted in a fault of the "W" phase selector switch.	Selector Switch barrier boards ruptured and the tapping windings on "W" phase damaged.	Transformer repaired at a cost of approximately [C.I.C] using Spare windings to replace "W" phase windings to effect quick return to site.
DDTS	H2 R ph.	[C.I.C]	17/12/2000	37	Transformer taken out of service due to collection of gas in Buchholz relay. DGA sample suggest Partial discharge/ sparking fault	Extensive on-site testing has confirmed partial discharges but could not locate.	Transformer retired and replaced with a three-phase spare. Held old H2 bank as a spare transformer. Estimated cost was [C.I.C].
MBTS	Tie Transformer W ph.	[C.I.C]	30/03/2004	49	Internal earth fault on tertiary of White Phase Unit	Winding Damaged.	Replaced with single phase spare.

MBTS	Tie Transformer W ph.	[C.I.C]	14/02/2005	50	Internal earth fault on tertiary of White Phase Unit. This is the spare unit installed in the previous failure on 30/3/2004. This failure is also similar to the previous failure.	Winding Damaged	Transformer bank was already being planned to replace due to lack of fault capability. Therefore, temporarily replaced with the 150 MVA country spare. Later replaced with 2 off 50 MVA Transformers (Tie plus spare).
TTS	B2 W ph. "B" unit	[C.I.C]	31/03/2007	45	Transformer tripped on gas protection followed by gas alarm due to a through fault.	Site testing confirmed winding failure with winding faults on LV and Tertiary and winding displacement. Also winding displacement in white phase "C" unit.	Replaced with a new 3 phase transformer. Also new foundations, etc.
TTS	B1	[C.I.C]	4/03/2009	23	Transformer tripped on gas protection followed by gas alarm approximately 1.5 hours after a close- in through fault.	DGA confirmed internal arcing fault and site tests indicated "A" phase LV and TV winding displacement and winding faults. Transformer removed from location. Fault found in "A" phase 66 kV winding. It was established that TV winding has inadequate short circuit strength for TV faults and Phase to Earth through faults. Neutral reactor helps.	Replaced with a new transformer.
MWTS	B1	[C.I.C]	31/01/2010	44	Transformer tripped on gas protection due to a close-in through fault. DGA was conducted and DGA was OK. Tripped from diff protection with gas alarm when re-energised.	Tapping winding displacement.	Replaced with the country spare and retired the failed transformer.
KTS	A2 W ph.	[C.I.C]	4/05/2011	40	Transformer tripped on gas protection and gas alarm came	Fault in "A" leg common winding – turn to turn and disc to disc within top 10 discs confined between two spacer blocks.	Replaced with a spare transformer (single phase) and failed transformer was repaired at [C.I.C] replacing all windings

					up. DGA confirmed an internal fault. High resistance found in the "A" leg common winding		with spare windings. The cost was [C.I.C].
BATS	B1	[C.I.C]	2015	45	OLTC internal flashover due to surface discharge between phases and cellulose based insulation. Contaminated oil.	The failure resulted in damage to the diverter, selectors and the B phase windings and possibly the core. Tapping winding damage.	Replaced with the SMTS Country Spare transformer.
FBTS	B1	[C.I.C]	2016	45	Internal tapping winding fault.	Extensive damage of A phase winding and OLTC.	Replaced with FBTS Metro Spare transformer.
RWTS	B2	[C.I.C]	2016	44	Internal fault due to deflection from short circuit forces. Paper was displaced during an oil change. The aged transformer was incapable of withstand short circuit force rating.	Unrecoverable internal damage.	Replaced with TTS Metro Spare.

AusNet

Level 31
2 Southbank Boulevard
Southbank VIC 3006
T +613 9695 6000
F +613 9695 6666
Locked Bag 14051 Melbourne City Mail Centre Melbourne VIC 8001
www.AusNet.com.au

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