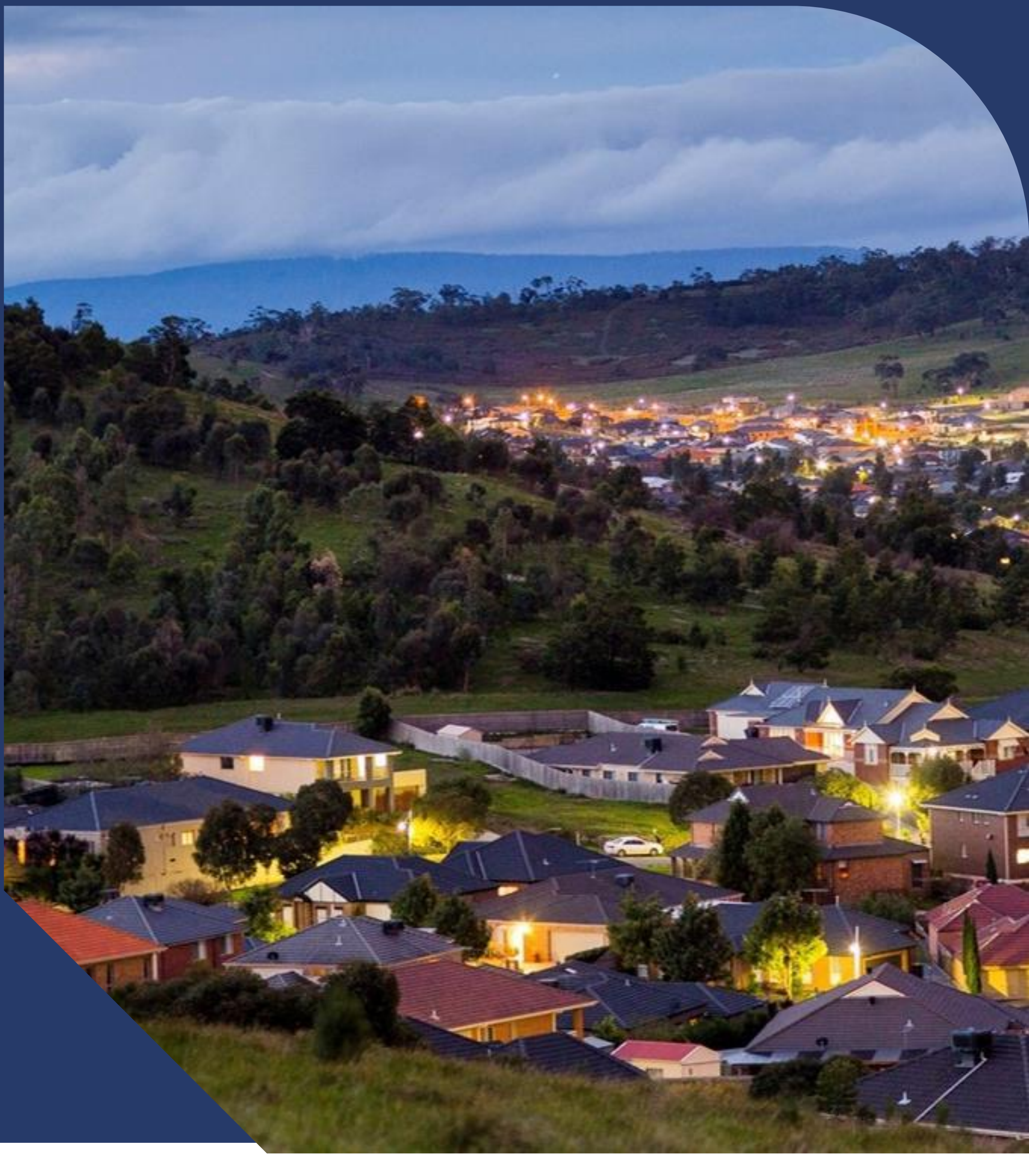
# Power Transformers and Station Regulators

## AMS – Electricity Distribution Network



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AusNet

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# 1. Abbreviations and definitions

| TERM | DEFINITION |
|---|---|
| PT | Power Transformer |
| OLTC | On Load Tap Changer |
| ONAN | Oil Natural Air Natural |
| ODAF | Oil Directed Air Forced |
| RIN | Regulatory Information Notice |
| Pof | Probability of failure |
| Cof | Consequence of failure |
| Zk | Work order Notifications associated with failures (unplanned power interruptions) |
| ZA | Work order Notifications associated with corrective actions from planned inspections |
| MTTR | Mean Time To Repair |
| RIP | Resin Impregnated Paper |
| RIS | Resin Impregnated Synthetic |
| OIP | Oil Impregnated Paper |
| SRBP | Synthetic Resin Bonded Paper |

# 2. Introduction

## 2.1. Purpose

The purpose of this document is to outline the inspection, maintenance, replacement, and monitoring activities identified for economic life cycle management of the fleet of zone substation power transformers and regulators in AusNet's Victorian electricity distribution network. This document is intended to be used to inform asset management decisions and communicate the basis for activities.

In addition, this document forms part of our 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

Included in this strategy is power transformers greater than 2MVA and voltage regulators (referred to as 'regulators'), within AusNet zone substations.

Excluded from this strategy is pole and pad mounted transformers, line regulators and 22kV regulators outside of zone substations, stand-alone station service transformers within zone substations. Replacements required for network augmentation are also excluded from this document as it is outside the scope of replacements based on risk.

## 2.3. Asset Management Objectives

The high-level asset management objectives are outlined in *AMS 01-01 Asset Management System Overview*.

The electricity distribution network objectives are stated in *AMS 20-01 Electricity Distribution Network Asset Management Strategy*.

# 3. Asset Description

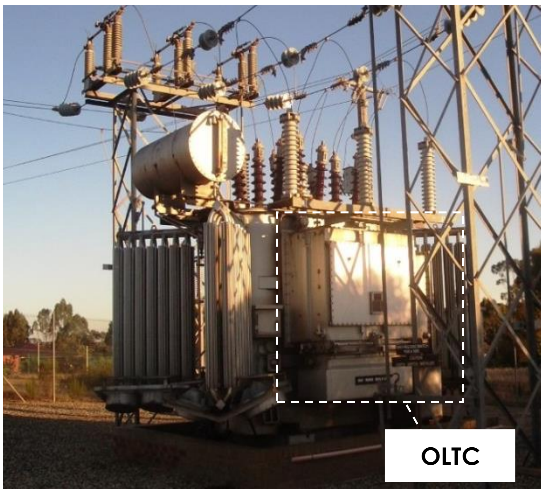
# 3.1. Function

Transformers are required to transfer power between circuits of different operating voltages. Typically zone substation transformers step the 66kV sub transmission network and the 22kV distribution network. The 66kV voltage level is required to transport large amounts of power over long distances with low resistive losses, whereas the 22kV network distributes the power to geographically diverse power consumers.

The power transformer fleet has nameplate ONAN (oil natural air natural) ratings ranging from 2 MVA to maximum continuous power ratings of 45 MVA. To maintain rated output voltage, 90% of power transformers are fitted with on-load tap changers (OLTCs), as illustrated in Figure 1.

**Figure 1: Typical Zone Substation Power Transformer with OLTC**


**Figure 2: Typical Station Voltage Regulator with OLTC**




Resistance in long radial circuits can result in a significant voltage drop. Regulators overcome this by transforming the voltage up so the voltage at end of the line remains within code despite the resulting voltage drop. The installation of a 66kV regulator within a zone substation can increase the voltage of a single feeder without increasing the voltage too much in the zone substation.

Regulators, as shown in Figure 2, are of similar construction and design to a power transformer, thus require a similar lifecycle management.

# 3.2. Population

The 2024 Category Analysis Regulatory Information Notice (RIN) 5.2 Asset Age Profile reports there are 150 power transformers within AusNet zone substations. The reports 168 regulators – 3% of this population are contained within zone substations and are within the scope of this strategy document. The other 97% of the population of regulators are 22kV regulators outside of zone substations and are managed according to the line voltage regulator strategy AMS 20-68.

## Population Considerations

The population profile for power transformers is crucial for effective lifecycle management. This profile includes detailed data on the quantity, types, locations, and specifications of these assets within the electrical distribution network.

A comprehensive understanding of the population profile allows asset managers to:

- **Identify critical assets**: Determine which power transformers are essential for maintaining the integrity and reliability of the network. For example, a particular high-capacity transformer serving a critical industrial area might be deemed essential and require more frequent inspections to ensure uninterrupted service.
- **Allocate resources efficiently**: Plan and allocate maintenance resources effectively by knowing the exact number and location of assets. For instance, knowing that a certain region has a high concentration of 66kV power transformers can help in scheduling maintenance activities more efficiently.
- **Risk management**: Assess and manage risks associated with different assets. For example, if the population profile indicates that certain transformers are in flood-prone areas, additional protective measures can be implemented in those areas.
- **Optimise maintenance schedules**: Develop optimised maintenance schedules based on the distribution and condition of assets. For instance, power transformers that form the backbone of feeder circuits from a zone substation might be scheduled for more frequent inspections and maintenance to prevent any potential failures.
- **Enhance reliability and safety**: Ensure that all components, including high voltage, medium voltage, and low voltage power transformers, meet the required standards for reliability and safety. For example, if the profile reveals that certain transformers have outdated insulation that no longer meets safety standards, these can be prioritised for replacement.
- **Support strategic planning**: Inform long-term strategic planning and investment decisions. For instance, the population profile might show that a significant portion of 66kV transformers in a rapidly developing suburban area need upgrading to support increased demand, guiding future investment in that region.

## Geographic Impact Areas

The AusNet electrical distribution network covers a significant portion of Victoria, including Melbourne's northern and eastern suburbs, and extends across eastern and north-eastern Victoria. This region encompasses a diverse range of geographic locations, each with specific environmental impacts on power transformers. Understanding these impacts is essential for effective asset management within the AusNet electrical distribution network.

Notable examples include:

- **High Wind Areas**: High wind areas, particularly in elevated regions and open plains, subject power transformers to significant stress and fatigue. Example: The structural integrity of transformers in the elevated regions of the Dandenong Ranges must be robust enough to withstand high wind speeds, ensuring they remain securely in place and do not fail under stress.
- **Corrosive Areas**: Coastal areas and industrial regions where salt and pollutants are prevalent can cause corrosion of metallic components in power transformers. Example: Regular maintenance and the use of corrosion-resistant materials are crucial to prolong the lifespan of these transformers. Transformers in coastal towns like Wonthaggi require regular inspections and maintenance to mitigate the effects of salt-induced corrosion.
- **Bushfire Areas**: Bushfire-prone areas, common in many parts of Victoria, pose a risk of fire damage to power transformer infrastructure. Example: Fire-resistant materials and strategic vegetation management around transformer installations are essential for reducing this risk. In the bushfire-prone regions of the Yarra Valley, transformers must be designed to withstand high temperatures, and installations must be cleared of nearby vegetation to prevent fire spread.
- **Flood-Prone Areas**: Areas prone to flooding can impact the performance and integrity of underground power transformers. Example: Proper waterproofing and drainage systems are essential to protect these assets. In regions like Gippsland, where flooding is more frequent, underground transformers must be installed with robust waterproofing measures to prevent water ingress and subsequent failures.
- **Seismic Zones**: Though less common, areas with potential seismic activity may require power transformers to be constructed with flexibility and resilience to absorb and dissipate seismic forces, reducing the risk of structural failure. Example: In areas near fault lines, transformers may need to incorporate seismic-resistant features to ensure stability during earth tremors.

These potential risks are treated in the design stage of transformer procurement.

## Population by Type

Within the scope of this strategy there is significant focus on power transformer as these constituted 97% of the population. The remaining 3% of this scope are 66kV station step-up voltage regulators.

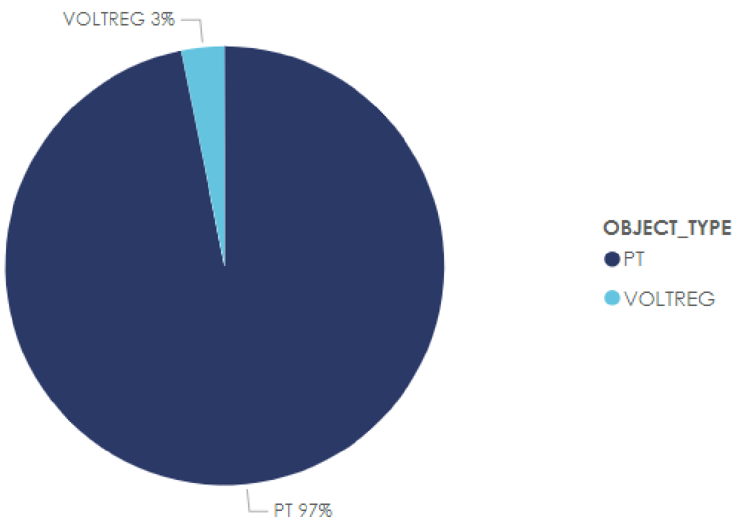



**Figure 3 - Relative population of Power Transformers and Stations Voltage Regulators**

**Power Transformers:**

- **Summary Explanation of Form and Function:** A power transformer consists of primary and secondary windings, an iron core, insulating materials, and a protective casing.
- **Purpose within the Asset Class:** The power transformer serves to transfer electrical energy between high-voltage and medium-voltage circuits, ensuring efficient power distribution across long distances with minimal losses.
- **Purpose within the Network Design**: The population of transformers comprises of units with high voltage windings of 11kV, 22kV and 66kV. The 66kV and 22kV were traditionally designed to be step down to reticulated low voltage networks 22kV and 6.6kV respectively. The 11kV units were designed as power station power supplies. The unit's range in rated power from 3MVA to 35MVA as per the nominal natural cooling (ONAN – oil natural air natural) apparent power rating.
- Reverse Power Flow: Due to the growth in embedded generation source – such as rooftop PV – there is a growing requirement for transformers to allow for reverse power flow, from LV network (22kV) into the sub-transmission network (66kV). New transformers are procured with a wider tapping range and reverse power capacity. Lack of capacity may in future lead to replacements based on LV generation constraints – not only failure risk or forward power flow, which has traditionally been the case.

**Voltage Regulators:**

- **Summary Explanation of Form and Function:** Stations voltage regulators consist of primary and secondary windings, an iron core, insulating materials, and a protective casing.
- **Purpose within the Asset Class:** The difference between a voltage regulator and a power transformer are the winding ratios are close to 1:1, and after often autotransformers where the secondary output is a tap of the primary winding. Voltage regulators are designed to have additional step-up taps to raise the output voltage while maintaining power.

- **Purpose within the Network Design**: They are used mid-way along long circuits, or at the start of very long circuits, to counteract resistive voltage drop. Stations voltage regulators are predominantly used on the sub-transmission network (66kV) and as a result are much larger than distribution regulators and are very similar to power transformers. The latter is the prime reason they are included in this strategy document.

## Population by Voltage and Rating

Figure 4 shows the profile of transformers by power rating and voltage. The majority of stations power transformers in the distribution network are 66/22kV ration with 20/33MVA and 10/13MVA (ONAN/ODAF).

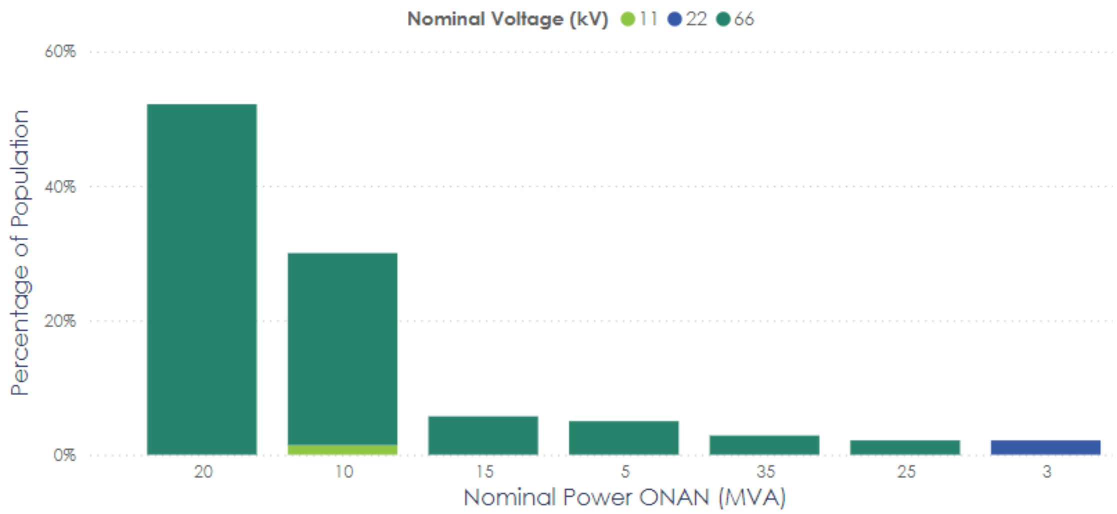



**Figure 4 - Equipment Percentage Transformers by Nominal HV Winding Voltage and Nominal Rating (MVA ONAN)**

## Population by Manufacturers

Unlike large population fleets, transformers are largely unique in their design and construction. Optimised designs of transformers began in 1960's reaching maturity in the 1980s. Transformers manufactured during this period of maturation transformers were predominantly sourced from local manufacturers – [CIC]. This group of transformers constitute 36% of the total population and for which design deficiencies are likely to be common. Otherwise, design issues relate to a specific design rather than a generation of transformer, or a transformer manufacturer.

CIC

**Figure 5 - Top 10 Transformer Population by Manufacturer**

## Population by Vector Group

In addition to having different primary/secondary voltages and manufacturers, the fleet of power transformers also have different 'vector groups'. The ways in which the three-phase windings in a transformer are connected determine which vector group the transformer belongs to.

Vector group, in addition to voltage, is a fundamental determinant of whether a spare transformer is compatible. Transformers connected in parallel must be of the same vector group due to the difference in tapping capabilities and impedance. Therefore, after a transformer failure, only a spare transformer of like vector group can be used as a replacement.

Table 3 lists the strategic spare transformers for the two major vector groups:

- Northern vector group – Delta/Star
- Central and East vector groups – Star/Star

The spares are overengineered to account for minor variations. Major variations in voltage and winding configuration mean a small percentage of the population are incompatible with the strategic spares, however this amounts to only 3% of the installed population. Figure 6 presents the population of transformers against their compatibility to spares.

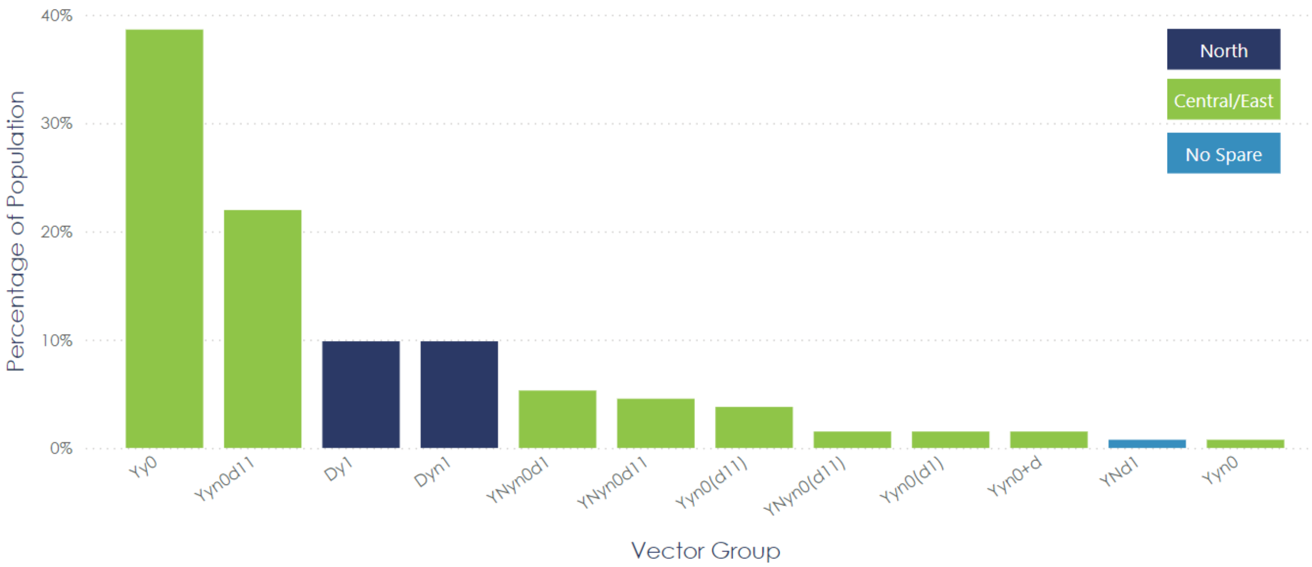



**Figure 6: Percentage of Total Transformer Fleet by Vector Group**

The 97% of the fleet of zone substation power transformers that are compatible with a spare will be replaced within four weeks in the event of a complete failure. The remaining 3% of transformers are incompatible with the spare transformers based on winding configuration or voltage – these include the:

- low quality water pump supply at YPS
- 22kV transformers in the Dandenong ranges – MDG, SFS, UWY

Due to the inbuilt redundancy at these stations, as well as their low population, it is a deliberate strategy to not hold spares for these transformers. In the event of a failure of one these transformers, new transformers will need to be procured – as per Table 2, the assumption is this will take 9 months on average.

As a result of their low population and relatively minor network impact, AusNet also doesn't hold spare station voltage regulators.

# 3.3. Age

## Age Considerations

Understanding the age profile of power transformers is crucial for effective asset management and lifecycle planning. Knowing the age distribution of these assets helps in predicting their remaining useful life and planning maintenance, upgrades, or replacements accordingly.

- **66kV Power Transformers**: The age profile of 66kV power transformers can indicate potential issues related to insulation degradation and metallic component corrosion. Older transformers may require more frequent inspections and condition assessments to ensure they continue to operate safely and efficiently. For example, proactive testing and monitoring of insulation resistance in older 66kV transformers can prevent unexpected failures and extend their service life.
- **22kV Power Transformers**: Over time, 22kV power transformers can experience insulation breakdown and mechanical failures due to thermal ageing and environmental stress. By analysing the age profile, asset managers can identify transformers that are at higher risk of failure and prioritise them for maintenance or replacement. For instance, replacing ageing insulation in 22kV transformers can prevent costly outages and enhance network reliability.
- **11kV Power Transformers**: 11kV power transformers can suffer from insulation deterioration and component fatigue as they age. Understanding their age profile allows for targeted interventions to replace or refurbish transformers that are most vulnerable. For example, replacing ageing 11kV transformers in older residential areas can reduce the risk of power outages and improve overall service quality.

## Age Profile

Figure 7 shows in service age of the fleet of stations power transformers and stations voltage regulators (represented by the legend SVR). It shows that 38% of the assets have been replaced within the last 20 years. It also shows a 22% concentration of assets the 41 – 50 year bracket and a substation tail of assets over 50 years. The population indicates the magnitude of the expected replacements - however, it doesn't show asset health or risk. Maintenance and monitoring strategies, as well as historical overdesign and modern design simulations, mean the effective conditional age is often lower than the chronological age. Risk based strategies also show that AusNet manages the risks rather than replacing assets when the reach a particular age.

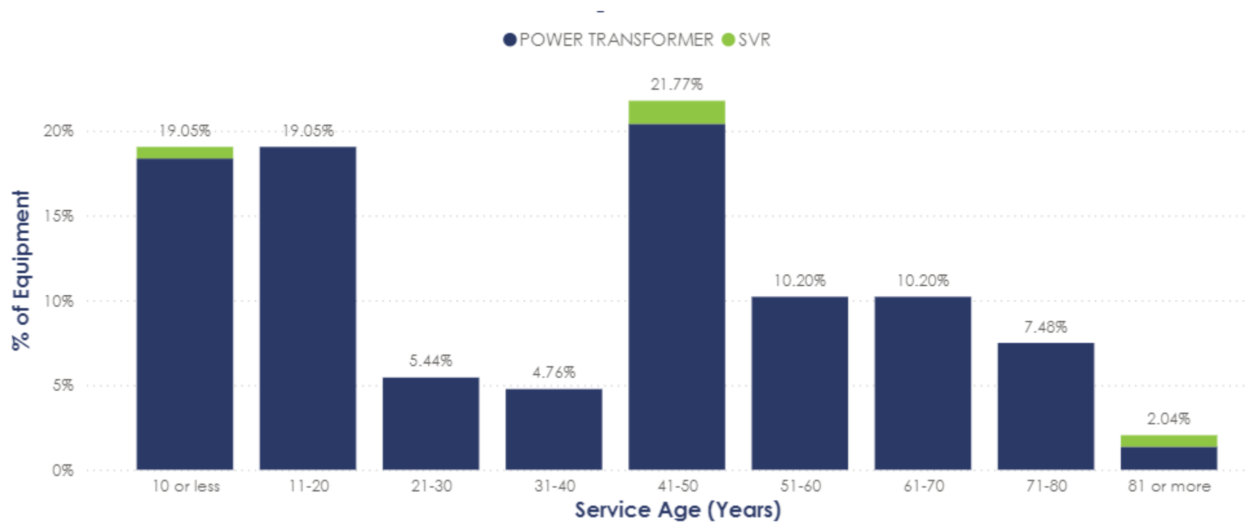



**Figure 7 - Population by Service Age**

# 4. Risk

AusNet maintains a risk management system designed in accordance with AS ISO 31000 Risk Management – Guidelines to ensure risks are effectively managed to provide greater certainty for the owners, employees, customers, suppliers, and the communities in which we operate.

The risk of each asset is calculated as the multiplication of probably of failure (PoF) of the asset and the consequence of failure (CoF). The risk is then extrapolated into the future accounting for forecast changes in PoF and CoF.

In the distribution network, AusNet aims to maintain risk. Risk treatments required to achieve this over time include replacement, refurbishment, and maintenance activities, and are developed based on current risk and extrapolated risk.

The overall approach to quantified asset risk management is detailed in AMS -01-09. Section 5.1, 5.2 and 5.3 of this document describe the considerations and methodologies to determine PoF, Cof, and risk treatments that are unique to Power Transformers and Station Regulators.

# 4.1. Probability of Failure

An asset is deemed to have failed when it does not meet the functional requirements for which it was acquired. Both quantitative and qualitative analysis is used to assess the condition of the asset to determine the probability of failure and to estimate the remaining useful life. AMS 01-09 describes the detail methodologies used in calculating and deriving the likelihood of a failure considering the four key factors - asset life, asset utilization, location and physical condition.

## 4.1.1. Failure Modes

Understanding failure modes is an important tool that supports measuring the criticality of assets, especially when assessing the risk of potential failures and their potential impact on the overall system. By identifying and analysing the various ways in which an asset can fail (including the root causes and mechanisms of failure), asset managers can better predict and mitigate risks. This understanding allows for a more accurate assessment of the probability of failure (PoF) and the consequence of failure (CoF), which, as noted above, is a core aspect of how AusNet approaches determining asset criticality.

Notable failure modes for power transformers are detailed below.

- **Insulation Degradation**: The insulation material can degrade over time due to thermal aging and environmental exposure, leading to reduced dielectric strength and potential electrical faults. Example: In power transformers, high temperatures can accelerate the decomposition of insulation materials, compromising their ability to prevent electrical arcing effectively.
- **Mechanical Wear**: Components such as windings, bushings, and tap changers can suffer from wear and fatigue, affecting the transformer's ability to operate correctly. Example: Frequent load variations may wear down the tap changers (OLTCs), leading to slower or incomplete voltage adjustments during operation.
- **Environmental Degradation**: Exposure to harsh environments, such as coastal areas or high pollution zones, can lead to corrosion of metallic components and degradation of insulation. Example: Salt spray in coastal regions can accelerate the corrosion of transformer tanks and fittings, leading to premature failure.
- **Moisture Ingress**: Water or moisture can penetrate the transformer, leading to corrosion of internal components and reduced insulation effectiveness. Example: In high humidity areas, moisture ingress can corrode the internal components of transformers, compromising reliability.
- **Thermal Overload**: Excessive current flow can cause the transformer to overheat, leading to thermal degradation and potential failure of the insulation system. Example: Sustained high current can cause transformers to overheat, leading to insulation breakdown and failure to maintain voltage stability.

- **Component Fatigue**: Repeated load cycling can cause fatigue in the transformer windings and other components, reducing their effectiveness over time. Example: Regular exposure to load fluctuations can wear out the windings, making them less reliable for future load demands.
- **Oil Degradation**: The insulating oil within the transformer can degrade over time due to oxidation and contamination, reducing its dielectric strength and cooling efficiency. Example: Moisture ingress or moisture migration may lower the dew point of the insulating oil, reducing the dielectric strength of the fluid insulation, and contributing to the degradation of cellulose solid insulation.
- **Oil Leaks**: Voltage regulators that use oil for insulation and cooling can develop leaks over time, reducing their effectiveness and increasing the risk of overheating. Example: Regular inspections can detect early signs of oil leaks, prompting timely maintenance to prevent failures.
- **Short-Circuits and Electrical Faults**: Electrical faults within the transformer windings can cause short-circuits, leading to sudden and catastrophic failures. Example: A fault in the primary winding can lead to a short-circuit, causing significant damage to the transformer and interrupting power supply.
- **Structural Integrity Issues**: The structural components of the transformer, such as the core and tank, can suffer from fatigue and damage due to mechanical stresses and environmental conditions. Example: Cracks in the transformer tank can lead to oil leaks and reduced cooling efficiency.
- **Seismic Activity**: In regions prone to earthquakes, seismic activity can cause mechanical stresses on transformers, leading to structural damage and potential failure. Example: Transformers in seismic zones may require additional reinforcement to withstand ground movements and maintain operational integrity.
- **Corrosive Sulphur:** Transformers purchased during the period from late 1990's to around 2006 were filled with oil that contained the highly corrosive compound Di Benzyl Di-Sulphide [DBDS]. The compound causes corrosive of metallic components of a transformer – copper windings and silver tap changer contacts. The addition of the passivator – Nypass – slows the degradation of the copper components, however, only that extraction of DBDS from oil will halt damage of silver components. In addition to the corrosion itself, there is an added chance corrosion of the silver plating causing AgS flakes in the oil leading to a dielectric failure.
- **66kV Bushings:** are condenser bushings that rely on internal insulation gradings comprised of conducting layer and insulating layers. These are subjected to higher stresses than 22kV and 11kV bushings. Breakdown of undulating layers due to moisture ingress or voltage excursions could result in a cascading insulation breakdown, whereas non-condenser bushings can rely in the internal oil quality alone.

### 4.1.2. Likelihood Assessments

In recent years AusNet has refined the probability of failure (PoF) methodology to make use of big data analytics and statistical analysis to make more effective use of available data. This allows each asset to be assigned a unique probability of failure and future extrapolation of probability of failure. Whereas assets were previously assigned a condition score (i.e. C1 to C5), they have now been assigned a value in the continuum between 0 and 1 then placed into a likelihood bucket for visualisation.

As per the methods of calculation described in AMS 01-09, the conditional PoF for power transformers and station regulators follows a Health Score methodology. This is driven by the relatively small asset population and the large number of historical measurements from insulating oil chemical testing and high voltage electrical testing.

The risk matrix shows the likelihood of a transformer failure for which replacement is the only feasible recovery. This is based on transformer replacement index produced in line with CIGRE Technical Brochure 761 – Condition Assessment of Power Transformers.

The oil and HV test results provide information on the condition of one of the 8 high level failure modes shown in

Table 1.

**Table 1 - Failure Modes**

| System | Failure Mode |
|---|---|
| Thermal & Mechanical | Accelerated cellulose aging |
| Thermal & Mechanical | Hot metal covered by paper |
| Winding & Core Dielectric | Major winding insulation |
| Winding & Core Dielectric | Winding insulation liquid |
| Winding & Core Dielectric | Physical and chemical contamination |
| Insulating Oil | Physical, Chemical Contamination, & Degradation |
| Insulating Oil | Degradation |

Each measurement is provided a health index (1-5, 1 best health, 5 worst health) based on empirical experience and knowledge of subject matter experts. The highest health index is chosen per failure mode and used as an input for the non-linear method of producing a health score – or replacement transformer assessment index (TAI) as per CIGRE Technical Brochure 761.

Health scores are created for all disposed transformers in addition to in-service transformers. The health scores for transformers that were replaced after a failure were used to produce a Weibull distribution – a characteristic health score and shape parameter. Health scores for the in-service transformers are compared to the characteristics to produce a percentage of characteristic health score. This is used to determine an 'effective' age, which is used as a starting point to extrapolate PoF into the future.

# 4.2. Consequence

Failure of a transformer or regulator has the potential of resulting in failing to supply customers with energy. There is also a possibility the failed asset injures an employee or member of the public or affect the environment.

The three key consequences of transformer and regulator failure are:

1. Safety – to customers and personnel
2. Community impact due to outages (unserved energy)
3. Environment – fire and oil leak

The detail methodology of the consequence assessment and its depiction in Risk Matrix are described in AMS -01-09.

### 4.2.1.1. Supply

AMS 01-09 documents the methods of monetising the consequence of an outage. Mean time to replace is an element that is particularly influential for transformers and regulators. Table 2 shows the values used in the risk assessment.

**Table 2 - Mean times to repair**

| Spare Transformer | MTTR | MTTR (hours) |
|---|---|---|
| **Spare available** | 4 weeks | 730 |
| **Spare to be procured** | 9 months | 6,575 |

### 4.2.1.2. Safety

The two main potential safety hazards stem from rupture of porcelain bushings and oil fires. The CIGRE technical brochure A2.37 Transformer Reliability Survey is referenced with determining probability of consequences for safety.

#### Bushing Failure

Failure of porcelain clad condenser transformer bushings pose a safety hazard to personnel within the vicinity of a transformer, which could result in a fatality. The monetisation of safety represents the cost to the community cause by the serious injury or fatality of an employee or member of the public.

22kV bushings are commonly non-condenser bushings. They don't relay as much on the internal physical construction to provide insulation; they are proportionally larger than 66kV bushings. As a result, they aren't subject to the same electrical stresses and are likely to fail with less force, resulting in a lower potential hazard.

New transformers are installed with RIP (resin impregnated paper) or RIS (resin impregnated synthetic) polymeric bushings, which fail in a benign manner and have negligible consequences.

#### Fire

For a transformer or regulator to become engulfed by fire substantial oil is required to leak into the bund and be ignited by an arc. For this reason, the potential hazard is lower than that of bushings, personnel need to be closer to the event to experience the effects. It is, however, large enough to consider as the risk that needs to be mitigated.

Oil pool could come from a rupture of the transformer tank from internal fault, or from an expulsion from a bushing turret resulting from a bushing failure. Transformers with OIP bushings are more likely to result in a large oil leak, whereas SRBP, RIP and RIS will likely retain the integrity of the internal oil sealing during a failure.

### 4.2.1.3. Environment

The environmental criticality of a transformer failure relates to the adequacy of the bund and oil treatment system. Inadequacy of the bund and oil treatment systems means that if a transformer lost all of its oil, the oil would oil be contained to the station.

### 4.2.1.4. Collateral Damage

An outcome of bushing failure or an oil fire is damaged to adjacent assets. Fire walls and physical separation are factors that reduce the impact. Event tree analysis is very similar to safety, however the impact is significantly less then safety when managing transformer risks, and is unlikely to drive additional mitigation measures.

# 4.3. Risk Treatment

Risk treatments are required to maintain risk by targeting reduction of PoF or CoF depending on the nature of the risk. Treatment measures include asset replacement, asset refurbishment, inspections, testing or system redesign, and are achieved through capital projects or operational expenditure. Risk treatment options are described in the section on 'Risk Treatment' in AMS 01-09.

## Replacement

Capital replacement is a major component of asset risk management. The prerequisites for replacing assets:

- replacement of an asset will result in a material risk reduction
- risks can't be feasibly managed through maintenance or refurbishment
- monetised risk exceeds the replacement cost – ie replacement is economic.

Replacement of transformers and regulators result from degradation of fundamental insulation structures. Component replacement may be able to delay the wholesale replacement where the fundamental insulation structures still have useful remaining life. Partial replacements include bushings and 'bolt on' type OLTCs. These are a high-risk activities and the risk of inducing failures as well as creating 'stranded' components are considered and may result in wholesale transformer replacements instead. In some cases, the safety risk of poor condition bushings may result in replacements just before transformer replacements to reduce safety hazard for project personnel – replacement with polymeric RIP and RIS busing substantially reduces potential safety consequence.

In many cases transformers are replaced before the risk due to deteriorating condition is too high. Network augmentation projects are undertaken to reduce their supply risk into the future.

## Component Replacement

OIP and SRBP bushings are failing tests at a high rate and should also be considered for condition monitoring.

Replacing a OLTCs and bushings are only 90% and 82% effective respectively, as these tasks have inherent risks, including compatibility, contamination, and quality of onsite installation.

## Refurbishment

The OPEX strategy helps prioritise maintenance activities within zone substations based on risk posed by transformer and regulators. The strategy focuses on restorative activities that reduce failure risk by returning conditional failure probability back in line with the characteristic life of the transformer or regulator. The strategy returns expected life rather than extending it.

## Oil processing

Corrective sulphur is an issue requiring a specific treatment strategy.

The initial strategy is to reduce the on-going deterioration to the copper conductors by adding the passivating additive - 'Nypass' – and monitor the levels. The passivator is used up during the service period while DBDS is present in the oil] until the unit can be reclaimed to reduce the DBDS down to an acceptable level of <5ppm

Also if there is any silver plating contacts [OLTC] and or terminal palms/lugs etc. the passivation does not halt the deterioration, therefore the second strategy is to process is to process the oil using specialised oil treatment equipment. The transformers are treated based on a prioritised risk level. Corrosive sulphur processing has the added benefit of removing moisture from the oil as well as reducing the acidity level related to ageing of the hydrocarbon strings themselves, improving the dielectric properties of the oil.

## Maintenance

The strategy consists of time-based inspections with follow-on condition-based maintenance, refurbishment, component replacements and complete transformer replacements to follow. Follow-on maintenance activities reduce risk by reducing the condition probability of failure or reducing the safety consequences inherent to a component.

# 5. Performance

## Performance Analysis

In the context of asset management for power transformers, assessing asset performance is a vital tool for effective lifecycle management. Performance information provides a comprehensive understanding of how these assets behave under various conditions, enabling asset managers to make informed decisions that enhance the reliability, safety, and efficiency of the electrical distribution network.

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.

Review of ZK (failure) notifications for transformers for the period 2015 to 2023 reveals that [CIC] of transformer failures relate to OLTC's (mechanism and diverter switch).

[CIC]

**Figure 8 - Failures per Subsystem**

Figure 9 shows that the majority of causes for OLTC failures relate to component wear out, seal wear out, and side effects of invasive maintenance.

[CIC]

**Figure 9 – Failures by Cause**

[CIC]

**Figure 10 – OLTC Failures by Damage Type**

## Targeted Activities (Performance Factors)

| REF | DETAILS OF MATERIAL CONSIDERATIONS |
|---|---|
| 01 | Scheduled oil sampling of OLTCs. Prioritising [CIC] and [CIC] OLTC oil sampling every 6 months. |
| 02 | Opportunistic condition based<br>• replacement of secondary wiring<br>• calibration/replacement of ESP gas relays<br>• calibration of winding temperature indicators. |

# 6. Related Matters

# 6.1. Regulatory Framework

## Compliance Factors

### Regulatory and Legislative Reference

Effectively managing compliance obligations specific to legislation and policies is a core element of Asset Class Planning and supports the sustainable operation and management of Network Assets. Ensuring adherence to relevant laws, policies and codes helps prevent legal and regulatory breaches, which can lead to significant penalties, operational disruptions, and reputational damage.

### Technical Standards and Procedures

Effectively managing compliance with technical standards and operational procedures is an important element of Asset Class Planning. Adhering to these standards ensures that the assets are designed, constructed, maintained, and operated in a manner that meets industry best practices, enhances safety, and ensures reliability. Compliance with technical standards helps prevent asset failures, reduces risks, and ensures interoperability within the electrical distribution network. For example, ensuring that all components of various asset types are installed and maintained according to Australian Standards can prevent unplanned failure and operational faults, enhancing network reliability.

# 6.2. External Factors

## Technical Factors

Understanding and managing the technical factors that can directly impact the lifecycle planning for Network Assets across all the AusNet Asset Classes is a core element of effective asset management. These factors encompass various design, engineering, and technical performance considerations that directly impact the ability to manage and maintain these assets efficiently. Ensuring that Network Assets meet specific technical performance standards is vital for maintaining the reliability and safety of the electrical distribution network. For example, selecting construction materials with appropriate durability and weather resistance is essential to prevent faults and ensure consistent performance under varying environmental conditions.

Specific known considerations are summarized below:

**High Voltage Testing**

High voltage winding electrical tests and bushing tests have been completed on zone substations since 2010. Continued off-line condition-based tests, together with DGA and oil tests would provide improved understanding of the condition of each transformer for a more focused condition based maintenance/replacement programs to be employed. The current strategy is to test every 8 years for mid-life to end of life transformers.

**OLTCs and Off-Circuit Switches**

Two issues relating to OLTCS are:

1. [CIC] OLTCs have an elevated risk of failure to do short service life.
2. [CIC] OLTCs have reverse power flow limitations, which is a consideration for network planning as distributed generation increases.

**Off Circuit Tap Switches**

Between the 1950s and the 1980s all transformers within the greater Melbourne metropolitan region were installed with a tap on the 22kV winding to achieve network planning flexibility. The LV Winding Off-Circuit Tap switches over time have an elevated likelihood of failure resulting from high resistance contacts due to spring aging and lowering contact pressure. As the switches have never been required, bridging out the switches is a means of removing this risk.

**Protection, Control, and Auxiliary Components**

Deterioration and malfunction of protection, control and auxiliary components, whilst minor in themselves, may lead to costly failures. The major risk factors are:

1. Many winding temperature indicators (WTIs) are either uncalibrated, or of unknown operability. Uncalibrated or inoperable WTIs cannot be relied on to provide controlled operation of transformers.
2. ESP type gas relays have not calibrated. They need to be calibrated under an intrusive outage or replaced. The non-operation of a gas relay may lead to larger consequences than a failure with a correctly operating relay. In addition to the unknown availably of ESP relays, they add confusion for routine maintenance - pressure test are undertaken for ESP relays in free breathing transformers, but this is not appropriate for sealed transformers, and could lead to maintenance induced failures.
3. Secondary wiring aging and oil leak induced deterioration of the conductor polymer insulation may lead to the maloperation of an auxiliary or control circuit. Wiring should have condition assessed and restorative work undertaken on an opportunistic basis.

**Short Circuit Withstanding Capacity**

Wilson 10MVA transformers manufactured between the 1960s to 1972 have 50 % short circuit capability. This may lead to early retirement of transformers due incapability and an elevated risk of failure as load and fault levels increase.

The through fault failure at [CIC] Zone Substation in [CIC] was a result of poor site assembly with the HV winding exit leads not secured correctly for through faults. [CIC] of the total population are of the same design, [CIC] transformers at [CIC] and [CIC] had HV winding exit leads secured.

## Targeted Activities (Technical Factors)

| REF | DETAILS OF MATERIAL CONSIDERATIONS |
|---|---|
| 01 | Continue off-line HV condition tests every 8 years for transformers in mid-life to end-of-life. |
| 02 | Assess and restore secondary wiring on an opportunistic basis – ie add on to other large maintenance works planned or unplanned. |
| 03 | Secure HV winding exit leads for outstanding 10MVA Wilson transformers. |

# Environmental Factors

Effectively managing obligations specific to environmental management is a core element of Asset Class Planning and supports the sustainable operation and management of Power Transformers. Ensuring adherence to relevant environmental laws and standards helps prevent legal and regulatory breaches, which can lead to significant penalties, operational disruptions, and reputational damage.

Significant oil leaks have become an issue that results in expensive repair work. One cause of oil leaks is the weather-related reduction of surface preserving paint systems. Repainting is a means of halting transformer deterioration – however this becomes costly when the original paintwork contains lead-based paint.

Changes to Environment Protection Act 2017 - coming into effect July 2020 - require strict control of regulating, prohibiting, monitoring of oil discharges to the environment underpinned by general environment duty (GED). Works to replace inadequate stations environmental systems commenced during the 2021-2025 regulatory period to reduce the risk of environmental damage in case of a major oil spill incident specifically oil escaping the site through stormwater or ground surfaces. To reduce risks these works should continue on a risk prioritised basis.

## Targeted Activities (Environmental Factors)

| REF | DETAILS OF MATERIAL CONSIDERATIONS |
|---|---|
| 01 | Consider feasibly of repainting transformers as a means of delaying replacement. |
| 02 | Continue risk-based upgrades to transformer oil environmental systems. |

## Stakeholder/ Social Factors

### Social Factors

Understanding social factors is essential for the effective management of critical network infrastructure assets. Social factors, including community expectations, public safety, and environmental impacts, play a significant role in shaping asset management strategies. Ensuring that these social considerations are addressed helps build public trust, maintain social license to operate, and enhance the organisation's reputation. For instance, ensuring that maintenance activities for power transformers do not disrupt local communities or pose safety risks is crucial for maintaining public support and compliance with social responsibilities.

### Stakeholder Factors

Understanding the requirements of stakeholders with a direct interest in the assets associated with the power transformers asset class is an important aspect of effective asset management. Key stakeholders, including customers, regulatory bodies, and industry partners, have specific expectations that influence asset management strategies and operational decisions. Ensuring clear communication and alignment with these requirements helps maintain regulatory compliance, enhance service reliability, and build robust partnerships. For example, customers expect reliable infrastructure and timely responses to issues, which requires minimal disruption during maintenance activities of power transformers. Similarly, regulatory bodies impose standards that must be adhered to, such as safety requirements for buildings and environmental systems, to avoid legal penalties and ensure operational legitimacy.

# 6.3. Internal Factors

## Training and Competency Factors

Effective training and competency development is a core element of asset class. Ensuring that asset managers, engineers, operational staff, and field personnel possess the necessary skills and knowledge is crucial for maintaining the reliability, safety, and efficiency of the asset network. Competent staff can effectively perform inspections, maintenance, and repairs, preventing asset failures and minimising downtime. Continuous training helps in keeping up with technological advancements, regulatory changes, and best practices, thereby enhancing overall asset management performance.

## Resource Management Factors

Resource Management is a core element of asset class planning for Network Assets. Proper oversight ensures that the management of AusNet's resource bases meets stringent quality and performance standards, which is essential for preventing asset failures, managing risks, and maintaining compliance with regulatory requirements. Effective resource management contributes to cost efficiency via activities such as leveraging the expertise of specialised in-house skills and contractors while avoiding hidden costs associated with inefficiencies and non-compliance.

There are three sub-categories of consideration for this factor, which are:

- Resourcing strategies
- Outsourcing
- Supply Chain Management

## Economic Factors

Economic factors significantly influence the lifecycle management of network assets, impacting financial stability, investment decisions, and overall network performance. Major contracts being tendered, such as those for infrastructure development, maintenance, and technology upgrades, can materially affect asset management. These contracts involve substantial investments, requiring rigorous management to align with long-term asset goals, mitigate risks, and control costs. Effective contract management ensures that service providers deliver value, supporting the network's reliability and performance while maintaining financial health.

Material developments and significant commercial agreements also play pivotal roles in the economic landscape of asset management. Commercial agreements, including customer service agreements, dictate service levels, performance metrics, and penalties, impacting operational priorities. Regular reviews of these agreements ensure adaptability to changing economic conditions, customer expectations, and regulatory landscapes. Additionally, planned renewal programmes and changes to asset types and purchasing strategies must be evaluated for their financial impact to ensure efficient resource allocation. By addressing these economic factors, AusNet can manage financial risks, optimise investments, and support robust lifecycle models, aligning financial planning with operational goals and regulatory requirements.

### Safety Factors

Safety is a paramount concern in the management of electricity distribution network assets, as outlined in **ESMS 20-01**. Effective asset management planning and activities are crucial for protecting employees, contractors, the public, and the environment from potential hazards associated with electrical infrastructure. Ensuring adherence to safety regulations and standards through diligent asset management helps prevent accidents, minimise risks, and maintain the integrity of the network.

Targeted asset management activities include conducting regular safety audits and risk assessments, maintaining a robust Bushfire Mitigation Plan, providing ongoing safety training and competency assessments, regularly reviewing and updating emergency response plans, engaging with the community to raise awareness about electrical safety, and adopting new technologies and practices to enhance network safety. By integrating these safety-focused activities into asset management planning, AusNet can effectively minimise safety risks "as far as practicable," as outlined in the Electricity Safety Act 1998 and reflected in **ESMS 20-01**.

Safety is a prime consideration of the asset risks assessment and risk mitigation plan. Asset components presenting an elevated safety risk are considered for replacements – eg oil filled porcelain condenser bushings with a high probability of failure.

## 6.4. Future Developments

### Technology and Innovation Factors

Effectively managing the process of tracking future technology developments and innovations is a core element of asset class planning. Staying informed about technological advancements ensures that asset management practices remain up-to-date, efficient, and competitive. Innovations can lead to improved materials, better monitoring systems, and enhanced maintenance techniques that increase the reliability, safety, and longevity of critical infrastructure. For example, advancements in diagnostic tools for detecting early signs of wear and the development of advanced materials for asset components can significantly enhance their performance and maintenance. **For technology and innovation, this is a process that looks to existing technologies, processes, or practices that have been proven in the market and have already been taken to market**.

### Continuous Improvement

Continuous Improvement (CIP) is a critical lynchpin process in the overall application of asset management, particularly for managing power transformers. CIP ensures that asset management practices remain effective, efficient, and adaptive to changing conditions and emerging challenges. By consistently seeking ways to enhance processes, technologies, and strategies, organisations can maintain high levels of performance, reliability, and safety. For example, regularly updating maintenance protocols for buildings, environmental systems, and security fences based on feedback and new insights can prevent issues before they become major problems, thereby extending the lifespan of critical infrastructure.

Best practice asset management promotes a culture of continuous improvement, encouraging organisations to regularly evaluate their asset management systems, identify areas for enhancement, and implement changes. This iterative process involves monitoring performance, analysing data, and applying lessons learned to refine practices. By focusing on CIP, organisations can ensure that their asset management activities remain dynamic, resilient, and aligned with best practices and strategic objectives. This approach not only enhances the overall efficiency and effectiveness of asset management but also supports long-term sustainability and success.

# 7. Asset Strategies

## 7.1. New Assets

A strategic asset strategy for the introduction of new assets provides high-level guiding principles and overarching goals for asset management, focusing on long-term planning and sustainability. This strategy outlines the aspects of asset upgrades or changes, detailing the conditions under which new assets may be introduced into the network. This is not a like-for-like replacement but rather a strategic change or upgrade to a different type of asset to enhance reliability, improve efficiency, and incorporate advanced technologies. It serves as a roadmap that is ideal to follow if possible, guiding the decision-making process for integrating new assets into the AusNet network.

### Targeted Activities (New Asset Strategies)

| REF | DETAILS OF MATERIAL CONSIDERATIONS |
|---|---|
| 01 | Continue to purchase standard power transformer sizes with sealed oil systems, composite/RIP bushings and vacuum tap changers |

## 7.2. Inspections and Monitoring

A strategic plan for inspections and monitoring provides high-level guiding principles and overarching goals for asset management, focusing on long-term planning and sustainability. This strategy outlines the ideal framework and objectives for conducting inspections and monitoring activities, such as enhancing reliability, improving efficiency, and incorporating advanced technologies. It serves as a roadmap that is ideal to follow if possible, guiding the decision-making process for establishing comprehensive inspection and monitoring protocols within the AusNet network.

### Targeted Activities (Inspection and Monitoring Strategies)

| REF | DETAILS OF MATERIAL CONSIDERATIONS |
|---|---|
| 01 | Continue annual oil sampling and analysis from main tanks and periodic oil sampling of problematic OLTCs, such [CIC] type. |
| 02 | Continue periodic oil sampling |
| 03 | Continue periodic HV testing |

## 7.3. Maintenance Planning

A strategic plan for maintenance provides high-level guiding principles and overarching goals for asset management, focusing on long-term planning and sustainability. This strategy outlines the ideal framework and objectives for conducting maintenance activities, such as enhancing reliability, improving efficiency, and incorporating advanced technologies. It serves as a roadmap that guides the decision-making process for establishing comprehensive maintenance protocols within the AusNet network. This involves creating a structured approach to regular maintenance activities to ensure optimal performance and longevity.

### Targeted Activities (Maintenance Planning)

| REF | DETAILS OF MATERIAL CONSIDERATIONS |
|---|---|
| 01 | Continue operations-based preventive maintenance on tap changers |
| 02 | Monitor level of corrosive sulphur passivator and top as required |
| 03 | Process oil for corrosive sulphur based on availability of treatment plant. Prioritise processing based on risk ranking |

# 7.4. Spares

Table 3 lists the three transformers that are in suitable condition to be used as a replacement in the event of a major transformer failure.

| Location | Region | Voltage (kV) | Phase Group | Nominal Rating (MVA ONAN) | Year of Manufacturer |
|---|---|---|---|---|---|
| [CIC] | Central/East | 66/22 | Yyn0(d1) | 20 | 2016 |
| [CIC] | North | 66/22 | Dyn1 | 15 | 2018 |

**Table 3 - Spare Transformers**

The strategy is to maintain the two transformers – one for the northern vector group and one for the central and east vector group. The spares are designed to support the majority of 'standard' transformers. The use of a spare transformer will trigger the procurement of a replacement.

In some cases, physical constraints may drive the temporary installation of a spare for the time it takes to procure and install a permanent replacement. Once a permanent replacement has been installed, the temporary becomes the spare again.

The strategy for the remaining transformers is procure when required and ensure the customer outage risk is mitigated by use redundancy and repair.

### Targeted Activities (Spares)

| REF | DETAILS OF MATERIAL CONSIDERATIONS |
|---|---|
| 01 | Procure a new spare transformer as the holdings are used |
| 02 | Monitor the load at risk for transformers with no spares |

# 7.5. Renewals Planning

A strategic asset strategy for renewals and replacements provides high-level guiding principles and overarching goals for asset management, focusing on long-term planning and sustainability. This strategy outlines the aspects of asset refurbishments or like-for-like replacements, detailing the conditions under which existing assets may be renewed or replaced within the network. This process ensures continued reliability and efficiency, manages obsolescence, and maintains adequate spares. It serves as a roadmap that is ideal to follow if possible, guiding the decision-making process for renewing or replacing assets within the AusNet network.

### Targeted Activities (Renewals Planning)

| REF | DETAILS OF MATERIAL CONSIDERATIONS |
|---|---|
| **01** | Continue risk-based replacements of transformer, regulators and bushings, based on probability of failure and consequence of failure |
| **02** | Continue to replace transformers and regulators based on changing customer demand and network voltage constraints. |

# 7.6. Decommissioning

A strategic asset strategy for decommissioning provides high-level guiding principles and overarching goals for asset management, focusing on long-term planning and sustainability. This strategy outlines the aspects of safely and efficiently removing assets from service, detailing the conditions under which decommissioning may occur. It ensures that the process is conducted in a way that minimises disruption, manages environmental impacts, and complies with regulatory requirements. It serves as a roadmap that is ideal to follow if possible, guiding the decision-making process for decommissioning assets from within the AusNet network.

### Targeted Activities (Decommissioning Strategies)

| REF | DETAILS OF MATERIAL CONSIDERATIONS |
|---|---|
| **01** | Salvage components of decommissioned transforms to assist in maintenance and minor repairs of transformers of similar design |

# 8. Legislative Reference

| STATE | REGULATOR | REFERENCE |
|---|---|---|
| VIC | WorkSafe Victoria | Occupational Health and Safety Act 2004 |
| National | Clean Energy Regulator | Clause 19 - National Greenhouse and Energy Reporting Act 2007 – 1 |
| National | Clean Energy Regulator | National Greenhouse and Energy reporting -Regulation 2008 |
| VIC | Environment Protection Authority | Section 25 -General environment Duty: Environment protection Act -2017 |

# 9. References

| NO. | TITLE | DOCUMENT TITLE |
|---|---|---|
| 1 | QMS 20-04 | Documented information Control |
| 2 | AMS 01-09 | Asset Risk Assessment Overview |
| 3 | AS ISO 31000 | Risk Management – Guidelines |
| 4 | AMS 01-01 | Asset Management System Overview |
| 5 | AMS 20-01 | Electricity Distribution Network Asset Management Strategy |
| 6 | PGI 02-01-04 | Summary of Maintenance Intervals – Distribution Plant Guidance and Information |
| 7 | SDM | Station Design Manual |

# 10. Schedule of revisions

| ISSUE | DATE | AUTHOR | DETAILS OF CHANGE |
|---|---|---|---|
| 1 | 22 Feb 2008 | AT, GL, DP | Initial draft |
| 2 | 2 Sept 2008 | PA, MC, AT, SD | Updated from review by NDD |
| 3 | 8 Oct 2008 | RP, TH, TD | Updated from review by NSG |
| 4 | 18 Nov 2008 | GL | Updated content and format |
| 5 | 22 Sept 2009 | GL | Updated from workshop with INS and NSD |
| 6 | 27 Oct 2009 | PA, MC, DP, GL | Review and update |
| 7 | 13 Nov 2009 | MC, DP, GL | Review and update |
| 8 | 24 Jun 2014 | JG,DM | Review, Update and Revised Structure |
| 9 | 20 Jun 2019 | C. Yates | Review and update for 2021-2025 period |
| 10 | 3 Apr 2024 | R Devine | Template, structure and general update |
| 11 | 6 Dec 2024 | C. Yates | Review and update for 2026-2031 period |

# Appendices

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