AMS 10-64 Instrument Transformers

2023-27 Transmission Revenue Reset

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Disclaimer

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Table of Contents

1 Executive Summary

This document is part of the suite of Asset Management Strategies relating to AusNet Services' electricity transmission network. The purpose of this strategy is to outline the inspection, maintenance, replacement and monitoring activities identified for economic life cycle management of instrument transformers.

1.1 Current Transformers:

This strategy covers the 1701 current transformers installed in terminal stations. Approximately 88.7% of the current transformers are located outdoor and have oil- paper insulation (64%), SF6 Gas (10%) or solid insulation (26%). Solid resin insulation types are mainly installed on indoor switchboards, outdoor power transformer neutrals and neutral balance CTs in capacitor banks.

Condition assessment shows approximately 73% of the total CT population are either in a "very good condition" (C1), "good condition" (C2) or "average condition" (C3). Approximately 27% of the population are either in "poor condition" C4 (17%) or "very poor condition" C5 (10%). The majority of the very poor condition CTs are outdoor 500kV [C-I-C] types and 66kV – [C-I-C] – 72/37 types.

The consequence of a failure was assessed based on community impact due to outages, safety, environment and collateral damage risks. Porcelain housed & oil filled current transformers pose a high risk of safety, collateral damage and environmental risk due to the inherent explosive and oil fire risk.

Risk based assessment on monetised consequence of failure was performed revealed an economically sound replacement program for high risk current transformers during the period 2022-27.

Proactive management of current transformers inspection, condition monitoring and replacement practice is required to ensure that stakeholder expectations of cost, safety, reliability and environmental performance are met. The summary of proposed asset strategies is listed below.

1.1.1 Asset Strategies

1.1.1.1. New Installations

- Install dead tank circuit breakers with integral CT's where possible up to 220kV operating voltage level
- Where associated CB is not being replaced, install polymer housed oil –paper insulated outdoor current transformers to latest specification except for polymer housed SF6 gas insulated outdoor current transformer for 500kV operating voltage
- Install high quality epoxy cast resin current transformers for operating voltages at and below 22kV.

1.1.1.2. Inspection

- Continue visual inspection during regular station inspections
- Continue annual annual non-invasive thermal and RF scanning

1.1.1.3. Maintenance

- Continue condition monitoring through regular oil sampling and DGA analysis, as per PGI 02-01-02.

1.1.1.4. Replacement

- Replace 12 off identified high risk C5 and C4 condition Current Transformer types: 500 kV [C-I-C] 06/550/5 types and 03 off 220kV [C-I-C] types
- Replace 27 identified high risk C5 and C4 condition Current Transformer types: 66kV [C-I-C] types

1.2 Voltage Transformers:

This strategy covers the 1405 voltage transformers installed in terminal stations. Voltage transformers consist of Capacitive Voltage Transformers (48.3%), Capacitive Voltage Dividers (4.3%) and Magnetic Voltage Transformers (47.4%). Approximately 85% of the VT population comprise of oil insulated voltage transformers, SF6 insulated (6%) in GIS installations and the remaining population is solid type epoxy or cast resin type VTs used for protection and measurements in indoor and outdoor arrangements.

It is observed that approximately 85% of the VT population comprise of oil insulated voltage transformers, SF6 insulated (6%) in GIS installations and the remaining population is solid type epoxy or cast resin type VTs used for protection and measurements. Majority of the very poor condition VTs are 66kV oil –paper insulation type bus MVTs.

The consequence of a failure was assessed based on community impact due to outages, safety, environment and collateral damage risks. Porcelain housed & oil filled voltage transformers pose a high risk of safety, collateral damage and environmental risk due to the inherent explosive and oil fire risk.

Risk based assessment on monetised consequence of failure was performed revealed an economically sound replacement program for high risk current transformers during the period 2022-27.

Proactive management of voltage transformers inspection, condition monitoring and replacement practice is required to ensure that stakeholder expectations of cost, safety, reliability and environmental performance are met. The summary of proposed asset strategies is listed below.

1.2.1 Asset Strategies

1.2.1.1. New Installations

- Install polymer housed oil –paper insulated outdoor inductive voltage transformers to latest specification up to 66kV operating voltage
- Install polymer housed oil –paper insulated outdoor capacitive voltage transformers to latest specification for higher than 66kV operating voltage
- At 22kV and below, install high quality epoxy cast resin voltage transformers
- Install CVT asset monitoring system (CAMs) on all CVTs installed in the transmission system

1.2.1.2. Inspection

- Continue visual inspection during regular station inspections
- Continue annual non-invasive thermal and RF scanning

1.2.1.3. Maintenance

- Continue condition monitoring through regular oil sampling and DGA analysis of MVT

1.2.1.4. Condition Monitoring

- Maintain CAMS to provide 100% functional coverage for CVT
- Investigate and introduce CAMS for CVD (used for AEMO quality of supply monitoring)

1.2.1.5. Replacement

- Replace 5 identified high risk C5 condition CVTs and MVT types: [C-I-C] types
- Replace identified high risk C4 condition 6 off 220kV [C-I-C] CVTs and 16 off 66kV [C-I-C] CVTs and MVTs

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 instrument transformers in AusNet Services' Victorian regulated electricity transmission 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

This Asset Management Strategy applies to all regulatory asset base outdoor and indoor type instrument transformers operating at 500kV,330kV,275kV,220kV,66kV, 22kV, 11kV and 6.6kV located in terminal stations.

It covers all types of current transformers (CT), magnetic voltage transformers (MVT), capacitive voltage transformers (CVT) and Capacitive Voltage Dividers (CVD). It excludes low voltage insulated current transformers integrated into power transformers and dead tank circuit breakers.

2.3 Asset Management Objectives

As stated in *AMS 01-01 Asset Management System Overview*, the high-level asset management objectives are:

- Maintain network performance at the lowest sustainable cost;
- Meet customer needs now and into the future;
- Be future ready;
- Reduce safety risks; and
- Comply with legal and contractual obligations

As stated in *AMS 10-01 Asset Management Strategy -Transmission Network*, the electricity transmission network objectives are:

- Maintain top quartile benchmarking;
- Maintain reliability;
- Minimise market impact;
- Maximise network capability;
- Leverage advances in technology and data analytics;
- Minimise explosive failure risk.

3 Asset Description

3.1 Asset Function

Instrument transformer is a general classification applied to current and voltage devices used to change currents and voltages from magnitude to another to perform a metering, alarm or protection relay function for isolation of unhealthy electrical circuit.

Current Transformers (CT) are used to measure the current flowing through a high voltage electricity circuit within the distribution network and transform this current into convenient quantities for use in protection and measurement & control relays.

Magnetic Voltage transformers (MVT) and Capacitive Voltage Transformer (CVT) are used to measure the operating voltage of a high voltage electricity circuit and transform this measurement into convenient voltages for use in protection and measurement & control relays.

3.2 Asset Population

AusNet Services has a total of 1701 current transformers (CT) and 1405 voltage transformers (MVT, CVT) installed in AusNet services terminal stations, as reported in 2018/2019 RIN.Outdoor CTs consist of hairpin and inverted head post-type with oil/paper insulation and porcelain or polymer housings at all voltage levels and as well as SF6 gas insulated CTs operating at 275kV and 500kV. There is also outdoor metal enclosed oil insulated type, indoor and outdoor epoxy encapsulated block type.
Capacitive Voltage Transformers (CVT) and Capacitive Voltage Divider (CVD) are single phase devices and Magnetic Voltage Transformer (MVT) is either single or three-phase voltage transformers. There are no capacitive VTs installed on circuits operating below 66 kV.
CVTs & CVDs are outdoor type with oil paper insulation in porcelain or polymer housings. MVTs are outdoor type with oil paper insulation in porcelain or polymer insulation. MVTs are also found with solid epoxy encapsulated block type insulation are used in indoor or outdoor applications.

3.2.1 Current Transformers

Figure 1 below provides the current transformer population by voltage and object type. Approximately 11.3% of the total CT population are in GIS Installations (CTGIN).

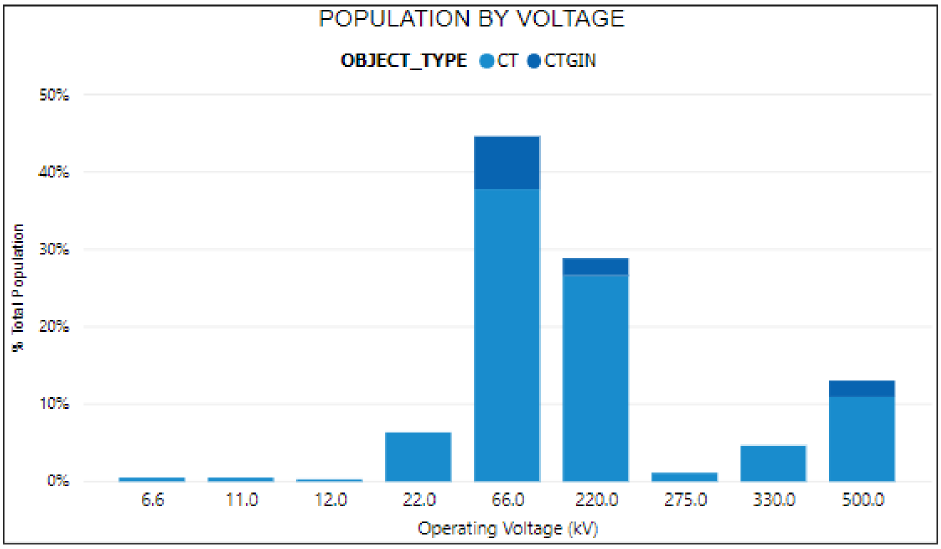

Figure 1 – Current Transformer Population by voltage and Object type

Figure 2 provides the current transformer population by insulation type. It is observed that approximately 64% of the CT population comprise of oil filled current transformers, SF6 insulated (10%) and the remaining population is solid type epoxy or cast resin type CTs used for protection and measurements and at capacitor banks.

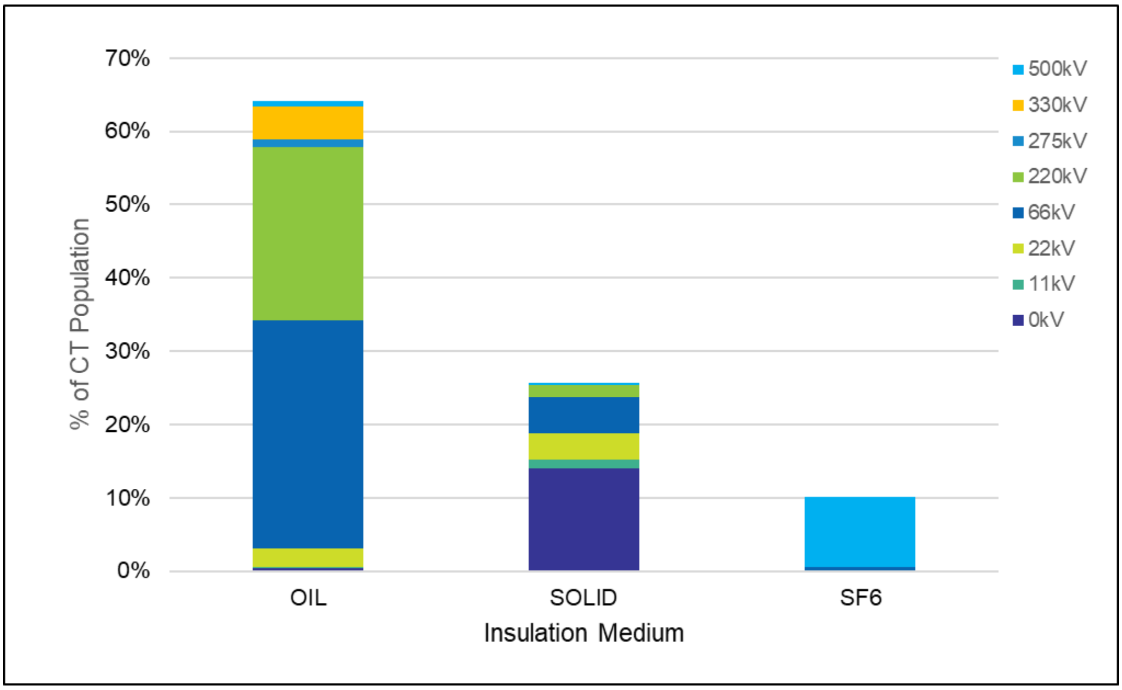

Figure 2 – Current Transformer Population by Insulation Medium

Figure 3 provides percentage of top 10 current transformer population by manufacturer. The most common manufacturer is [C-I-C] that contributes to 40.1% followed by [C-I-C] (16.5%) and third [C-I-C] (10.4%) and they are generally newer types.

[C-I-C]

Figure 3 – Current Transformer Population by Manufacturer (Top 10)

3.2.2 Voltage Transformers (MVT, CVT, CVD)

Figure 4 below provides the voltage transformer population by Object Type. Approximately 52.6% of the total 6.6kV - 500kV Voltage transformer population consist of CVT (48.3%) and CVDs (4.3%). CVTs are mainly at 220kV (36.4%) and 500kV (6.8%) of the total voltage transformer population. Magnetic voltage transformers (MVT, VT and VFTST) are mainly located at 66kV system (16.9%). Indoor type are those shown as VTSWCHBD and mainly at lower voltages.

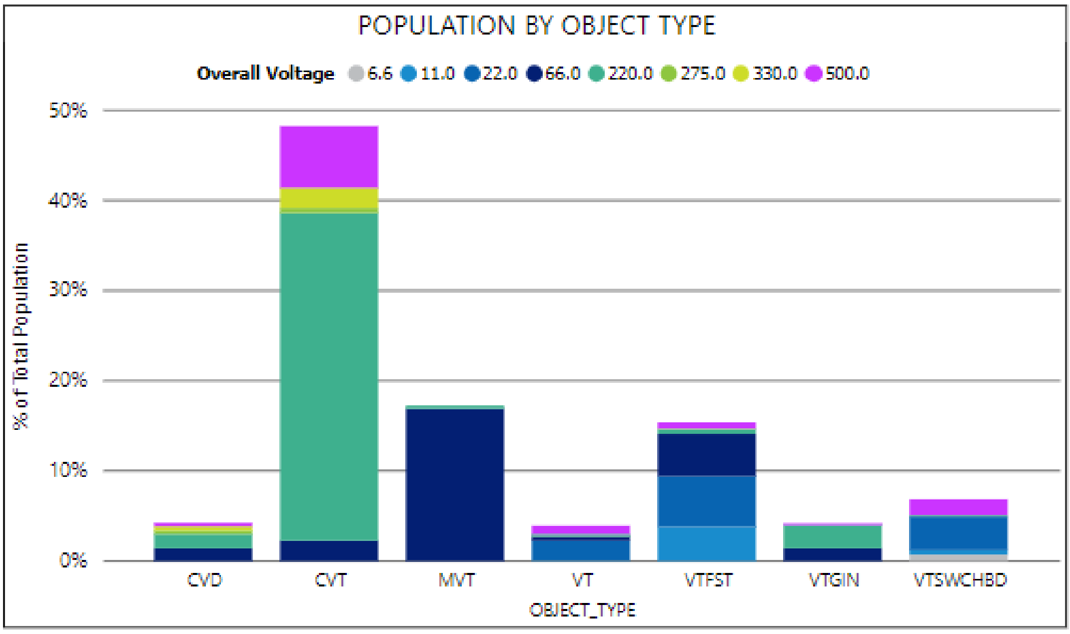

Figure 4 – Voltage Transformer Population by Object type

Figure 5 provides the voltage transformer population by insulation type. It is observed that approximately 85% of the VT population comprise of oil insulated voltage transformers, SF6 insulated (6%) in GIS installations and the remaining population is solid type epoxy or cast resin type VTs used for protection and measurements.

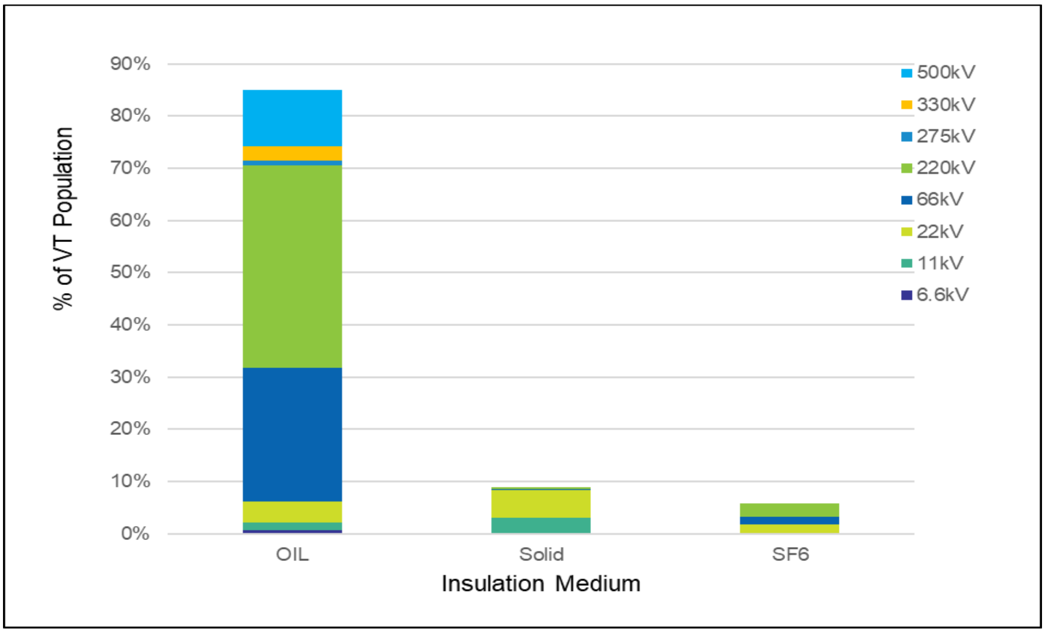

Figure 5 – Voltage Transformer Population by Insulation Medium

Figure 6 provides percentage of top 10 voltage transformer population by manufacturer. Out of the top 10 population, [C-I-C] contributes to 29.8% followed by [C-I-C] (24.7%), [C-I-C] (15.4%) contribute to 69.9% of the top 10 population and these three are generally newer types.

[C-I-C]

Figure 6 – Voltage Transformer Population by Manufacturer (Top 10)

3.3 Asset Age Profile

3.3.1 Current Transformers

The average service age of all 6.6kV -500kV current transformers is 19.1 years. Figure 7 below provides the age profile of all current transformers by service voltage. It is observed that approximately 3.3% of the population are more than 50 years of age and approximately 2% is due to 66kV and 220kV current transformers.

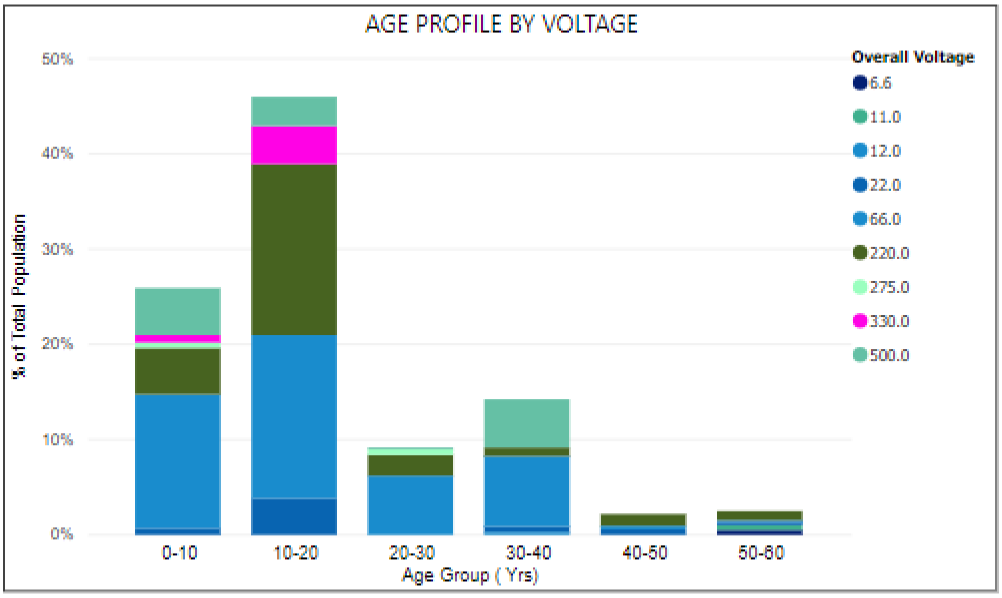

Figure 7 - Current Transformer Age by Service Voltage

Figure 8 below provides the age profile of 66kV -500kV CTs by top 10 manufacturer type. [C-I-C] and [C-I-C] make constitute to 2.1% of the CT population which are more than 40 years old.

[C-I-C]

Figure 8 - Age profile of 66kV -500kV Current Transformers by Manufacturer (top 10)

3.3.2 Voltage Transformers (MVT, CVT, CVD)

The average service age of all voltage transformers is 20.1 years. Figure 9 below provides the age profile of all voltage transformers by service voltage. It is observed that approximately 9.87% of the population are more than 50 years of age and approximately 5.6% is due to 66kV and 220kV voltage transformers.

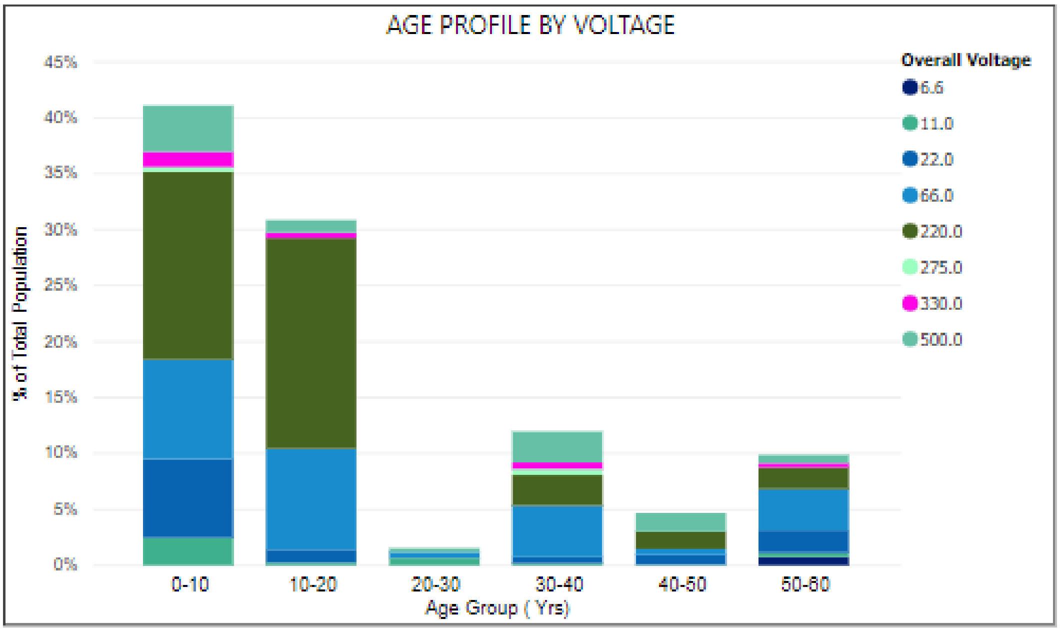

Figure 9 - Voltage Transformer Age by Service Voltage

Figure 10 below provides the age profile of 66kV -500kV VTs by top 10 manufacturer type. [C-I-C] (3.6%) and [C-I-C] (2.8%) constitute to 6.4 % of the VT population which are more than 50 years old.

[C-I-C]

Figure 10 - Age profile of 66kV -500kV Voltage Transformers by Manufacturer (top 10)

3.4 Asset Condition

Following key factors were used to determine the health Score of Instrument transformers:

1. Oil DGA Score based on oil and DGA analysis
2. Asset Score based on 80% Oil score and 20% age score.
3. Fleet Score based on fleet failure history, technical issues and technical obsolescence.
4. Overall Health Score based on 60% asset score and 40% of fleet score.

The Table 1 provides a definition of the various condition scores and recommended action.

Table 1: Condition Score definition and recommended action

Condition Score	Condition Description	Summary of Details of Condition Score	Remaining Service Potential %
C1	Very Good	Instrument transformers are typically new, with no oil leaks or defects.	95%
C2	Good	Instrument transformers have typically been in service for a number of years. Typically, very few minor defects and no history of any major failures and oil condition is satisfactory.	70%
C3	Average	Advancing deterioration. Occasional oil leaks but typically no history of any major failures or urgent replacements. Instrument transformers are still fully serviceable, but more attention is to be paid to deterioration rates. Oil condition is satisfactory.	45%
C4	Poor	Advanced aging. Oil leaks and failure of rubber sealing bellows may be becoming more evident. Some units may have been replaced. Autopsies and laboratory testing of suspect types are planned to better understand the deterioration mechanisms. Major failures may have occurred requiring enhanced monitoring. The risk of individual failures is tending upwards. Spares parts such as replacement bellows increasingly scarce and have to be salvaged from removed units. Oil condition is becoming poor and need DGA monitoring more than normally required.	25%
C5	Very Poor	These units have reached end of life and high risk of failure. Failure mechanisms may be known through autopsies and laboratory investigations from removed units. Major failures may have occurred and there will be a history of replacements. Enhanced monitoring, such as oil dissolved gas analysis (DGA) or RF scanning may be scheduled. There may be high enough safety concerns over the risk of major failure that	15%

		site access restrictions are implemented. There are no longer like spares available.	

3.4.1 Current Transformers

Condition profile of transmission current transformers by voltage is shown in Figure 11. It is observed that approximately 9.9% of the current transformers are in very poor condition (C5) comprise of 66kV (4.6%) and 220kV (2.2%), 500kV (3%) and 22kV and below (0.2%) of the total CT population. Analysis show that the worst five C5 condition Manufacturer -Models were found to be 500kV - [C-I-C]i 50SC, 220kV- [C-I-C] and 66kV – [C-I-C] – 72/37 models.

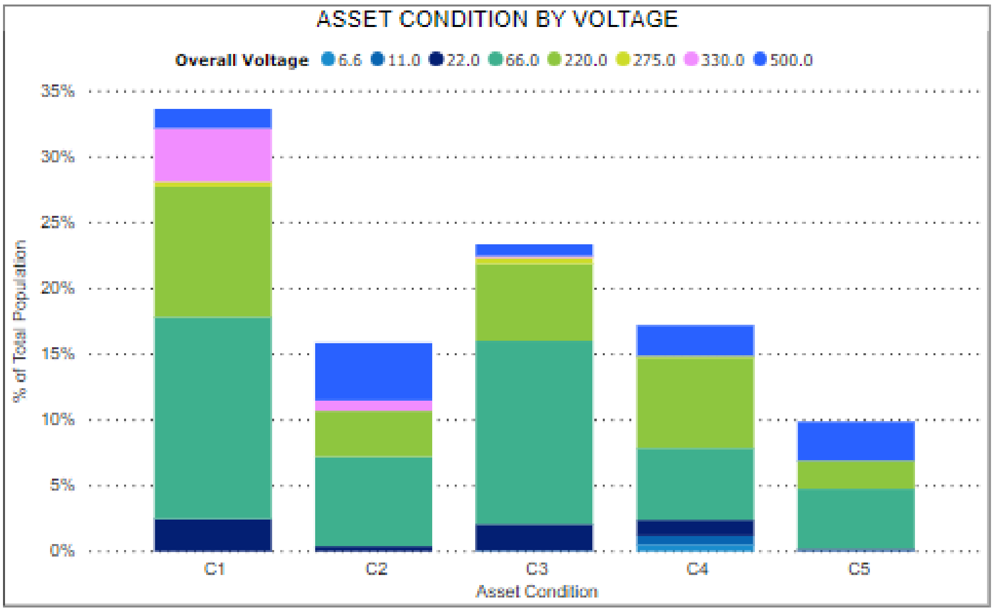

Figure 11 - Condition Profile of transmission Current Transformers by Voltage Class

Transmission current transformer asset condition score vs age profile is shown in Figure 12.

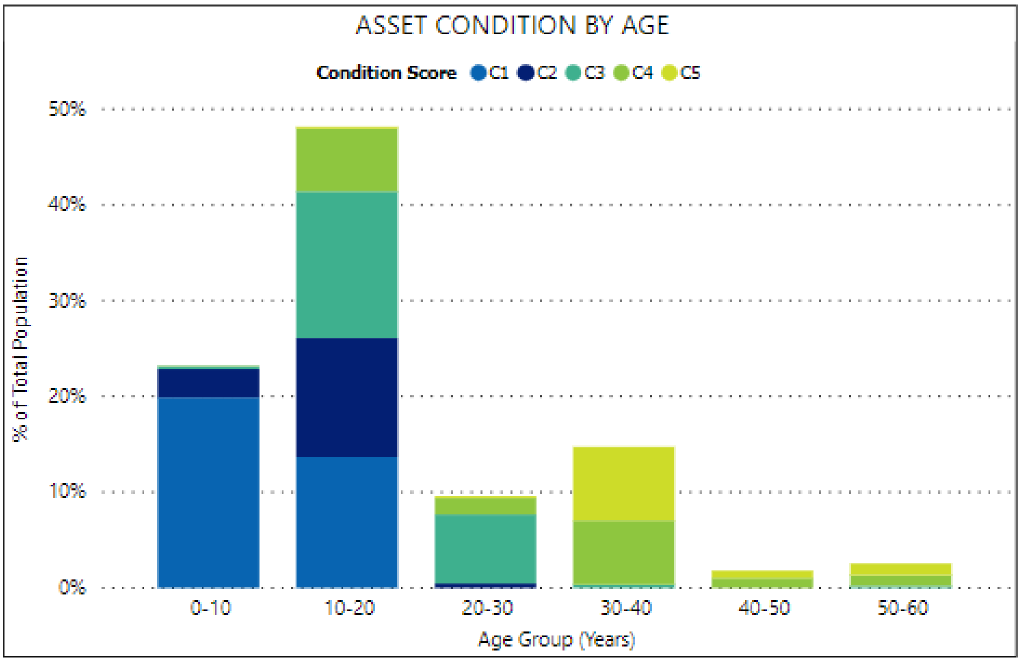

Figure 12 – CT Asset Condition vs Age

It is noticeable that there is a population of [C-I-C] polymer housed CT installed 10-20 years ago exhibiting advancing deterioration signs through DGA gas indications that are under investigation with supplier.

3.4.2 Voltage Transformers (MVT, CVT, CVD)

Condition profile of transmission voltage transformers by voltage is shown in Figure 13.
It is observed that 10.8% of the voltage transformers are in very poor condition (C5) out of which 220kV (2.7%), 500kV (2.6%) ,66kV (2.4%) ,275 kV & 330kV (1.4%) and 22kV and below (1.7%) of the total population.

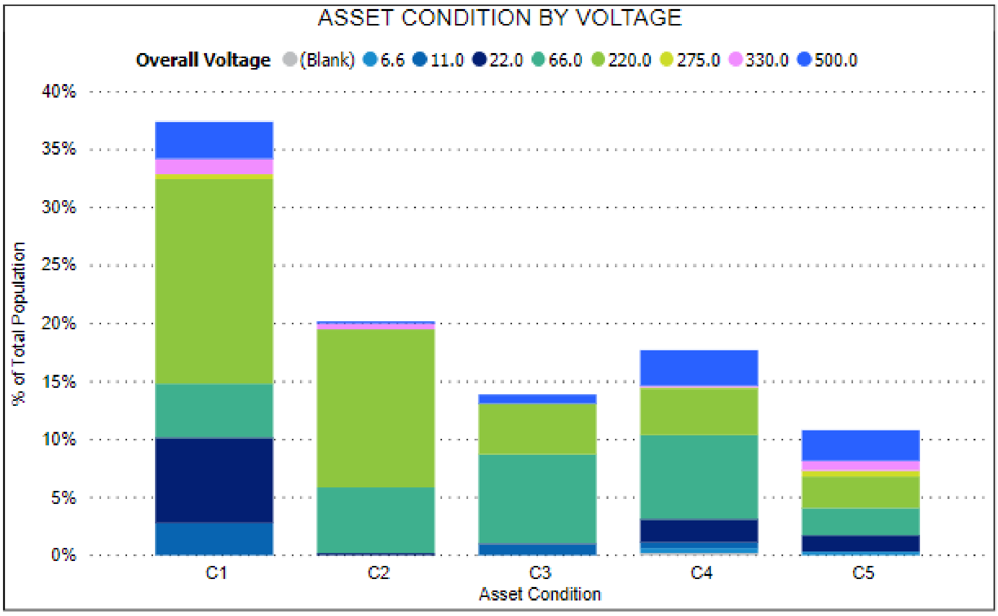

Figure 13 - Condition Profile of Transmission Voltage Transformers by Voltage Class

Transmission voltage transformer asset condition score vs age profile is shown in Figure 14.

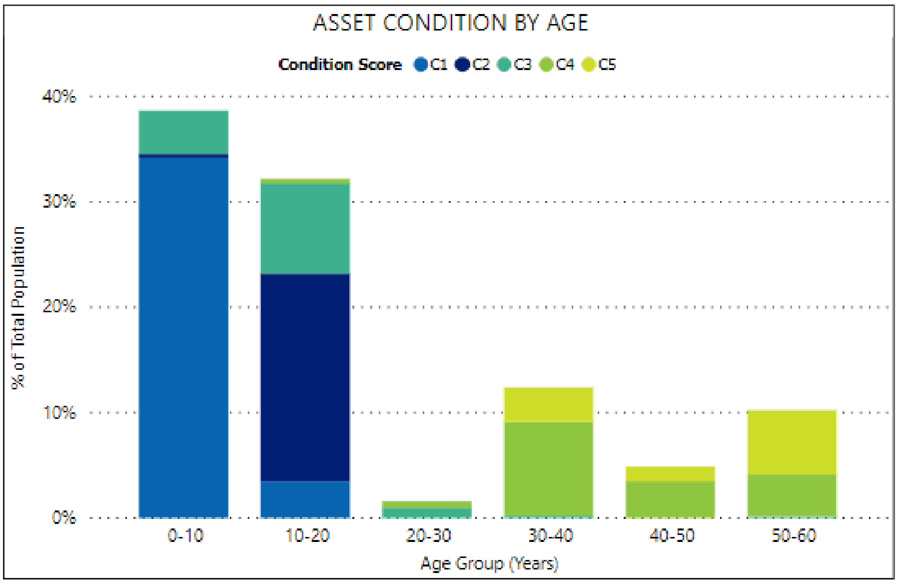

Figure 14 – VT Asset Condition vs Age

Further analysis reveals the following models typically were in poor condition:

- 66kV [C-I-C] type VTs were found to be in very poor (C5) and 66kV [C-I-C] types were found to be in poor condition (C4).
- 220kV [C-I-C], [C-I-C] models were found to be in C5 condition.

- 275kV and over, 330kV [C-I-C] types were found to be in very poor(C5) condition.

3.5 Asset Criticality

Asset Criticality was determined by considering the following consequences of instrument transformer failure with the failure effects mentioned below.

1. Safety impact,
2. Community impact due to outages (unserved energy)
3. Environment impact
4. Collateral damage

Asset criticality is the severity of consequence in a major failure of an instrument transformer at a certain location due to above failure effects irrespective of the likelihood of the actual failure. This gives an idea of circuit breaker types, located critical locations which represent the total value of risk $.

Safety impact is assessed on catastrophic failure risk and it depends mainly on explosive failure mode of porcelain bushings associated with older oil filled current and voltage transformers.

Modern oil filled current and voltage transformers are provided with polymeric bushings and the safety risk associated with transformer explosion is much lower.

Epoxy cast resin type CTs and MVTs are used at 22kV and below voltages in indoor switchboards and power transformer neutral applications and the safety risks associated with them are lower.

Community impact due potential value of unserved energy is estimated based on a 2-hour outage for restoration of supply to customers by alternative means when alternative means are available.

3.5.1 Current Transformers

The Figure 15 shows the Relative asset criticality based on Service Voltage.

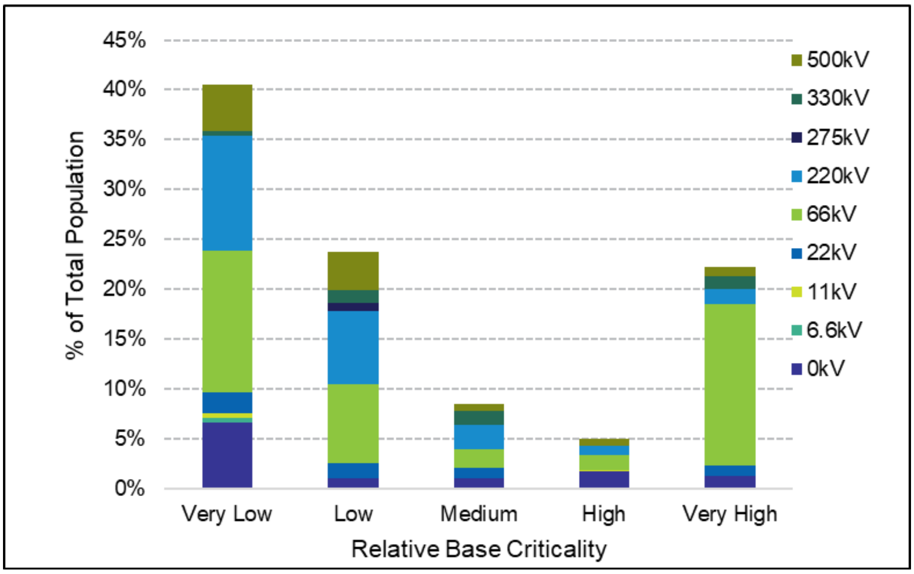

Figure 15 – Relative Base Criticality by Service Voltage

Following observations are made on asset criticality:

- Approximately 40.5% of the CT population have a very low criticality risk and mainly at 66kV (14.3%), 220kV (11.4%), 22kV & below (9.6%) and 330kV & 500kV (5.1%). Their market impact was found to be very low.

- Approximately 22.2% of the CTs fall into the very high criticality category (refer figure 17) and 16.2% of the population is due to 66kV CTs. Approximately 5% are due to C4 and C5 condition CTs. (Notably [C-I-C] types fall into this category among other types.)

3.5.2 Voltage Transformers (MVT, CVT, CVD)

The Figure 16 shows the Relative asset criticality based on Service Voltage and Asset Condition of VTs.

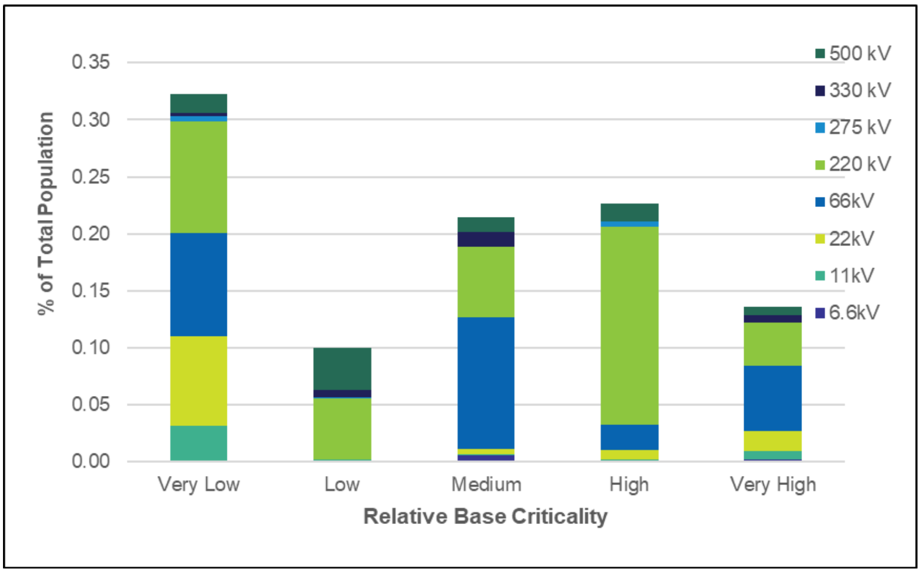

Figure 16 – Relative Base Criticality by Service Voltage

Following observations are made on asset criticality:

- Approximately 32% of the VT population have a very low criticality risk at all voltages. (refer figure 18) They are mainly on 66kV & below (20%) and the remaining are at 220kV (10%) and above 220kV (2%).Their market impact (VCR) effect was found to be very low.

- Approximately 14% of the VTs fall into the very high criticality category (refer figure 18) and approximately 8.5% are mainly on 66kV and below and the remaining are at 220kV and above (5.5%) CVTs, mainly due to high market impact (VCR) due to their critical physical location in the network. Approximately 26% are due to C4 and C5 condition CTs. (Notably 66kV [C-I-C] types fall into this category among other types.)

3.5.3 Relative Base Criticality

The applied interpretation of Relative Base Criticality for CTs and VTs in Section 3.5.1 and 3.5.2 is shown in Table 2.

Table 2: Interpretation of Relative Base Criticality

Relative Base Criticality	Criticality Banding	Definition
Very low	1	Total failure effect cost < 0.3 times Replacement Cost

Low	2	Total Effect Cost is between 0.3 – 1.0 times of replacement cost
Medium	3	Total Effect Cost is between 1 - 3 times of replacement cost
High	4	Total Effect Cost is between 3 -10 times of replacement cost
Very high	5	Total Effect Cost exceeds 10 times of replacement cost

3.6 Asset Performance

Life cycle management of transmission instrument transformers involve periodic routine inspections, annual non-invasive thermal and RF scanning and condition monitoring of oil. Most transmission instrument transformers are hermetically sealed and very little corrective work can be performed economically on them.

Table 3 shows the overall instrument transformer fleet ZA notification rates for all voltage classes. It is noted that the number of ZA notifications during the period 2015-2019 was about 69.2% for current transformers compared to voltage transformers (30.8%). Approximately 14.8% total notifications were due to CVTs. Increase in notification rate for current transformers is due to additional follow up action required in 2016 due to a major system incident which is explained in section 3.6.1.1.

Object Type	Total Count of ZA Notifications 2015-2019	Count of Equipment	Average Notification Rate per object type	Average Notification Rate per object type per year
CT	270	169	1.598	0.32
CTGIN	2	2	1.000	0.20
CVD	5	3	1.667	0.33
CVT	58	39	1.487	0.30
MVT	21	16	1.313	0.26
VTFST	34	17	2.000	0.40
VTGIN	2	2	1.000	0.20
VTSWCHBD	1	1	1.000	0.20
Total	**393**	**249**	**1.578**	**0.32**

Table 3 – Number of ZA Notifications per instrument transformer object Type 2015 – 2019

3.6.1 Current Transformers

AusNet Services performs condition monitoring of oil in current transformers where oil sampling is possible. The dissolved gas analysis (DGA) results for current transformers are a useful predictive maintenance method of determining the condition of the oil/paper insulation systems. DGA results provide understanding of the unit's serviceability. AusNet Services investigates all major failures, fleet issues associated with poor DGA results and trend analysis and tracks customer outages due to current transformer failures.

3.6.1.1. Corrective Work Order Analysis

Figure 19 provides the Number of ZA Notifications per current transformer by voltage during the period 2015 – 2019. It is noted that 63% of the number of ZA notifications during the period 2015-2019 were initiated in 2016. The increase of ZA notifications during the 2016 is mainly due to follow-up planned inspections and DGA oil sampling carried out on current transformers in terminal stations operating at 66kV and above following a catastrophic 220kV current transformer failure occurred in 2016 at Richmond Terminal Station (RTS).

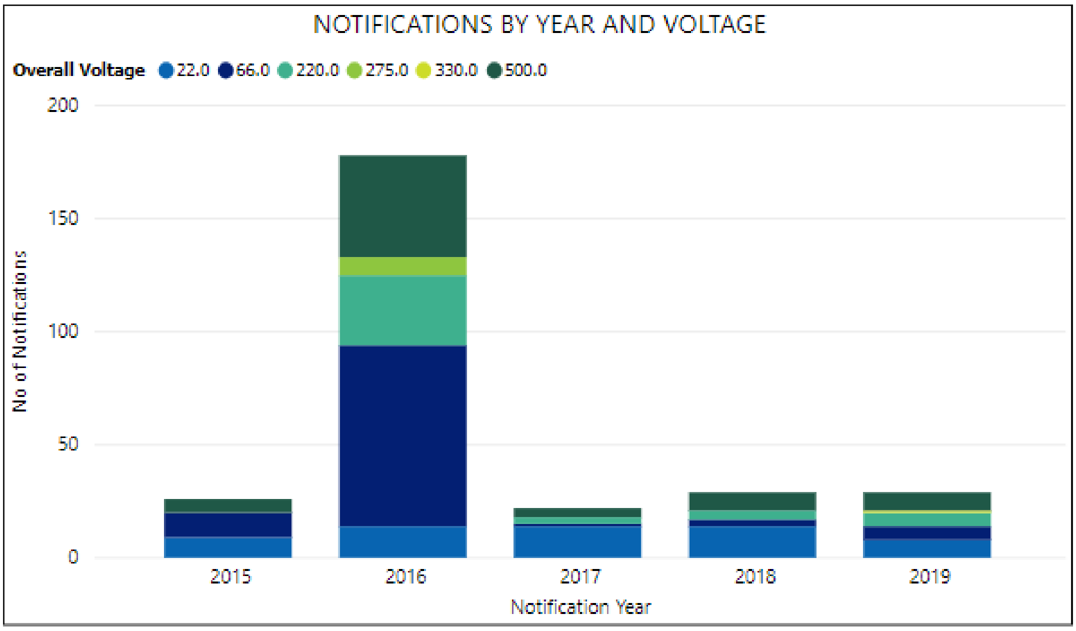

Figure 17 – Number of ZA Notifications per current transformer vs Voltage 2015 – 2019

Figure 18 provides the Number of ZA Notifications per CT manufacturer model during the period 2015 – 2019. [C-I-C] (66kV) had been common CT which had highest ZA notifications throughout the period 2015-2019. 500kV [C-I-C] and 220kV [C-I-C] types had the next highest ZA notifications. These three types together contributed to 74% of the ZA notifications in the year 2019.

[C-I-C]

Figure 18 – Number of ZA Notifications per CT Manufacturer 2015 – 2019 (top 10)

Figure 19 provides the Number of CT ZA Notifications Vs Defect type (top 10) during the period 2015 – 2019. Poor oil results (DGA) contributed to 79.5% of the CT ZA notifications during the year 2016. Corrosion and oil leaks contributed to 47.3% of CT ZA notifications in 2019.

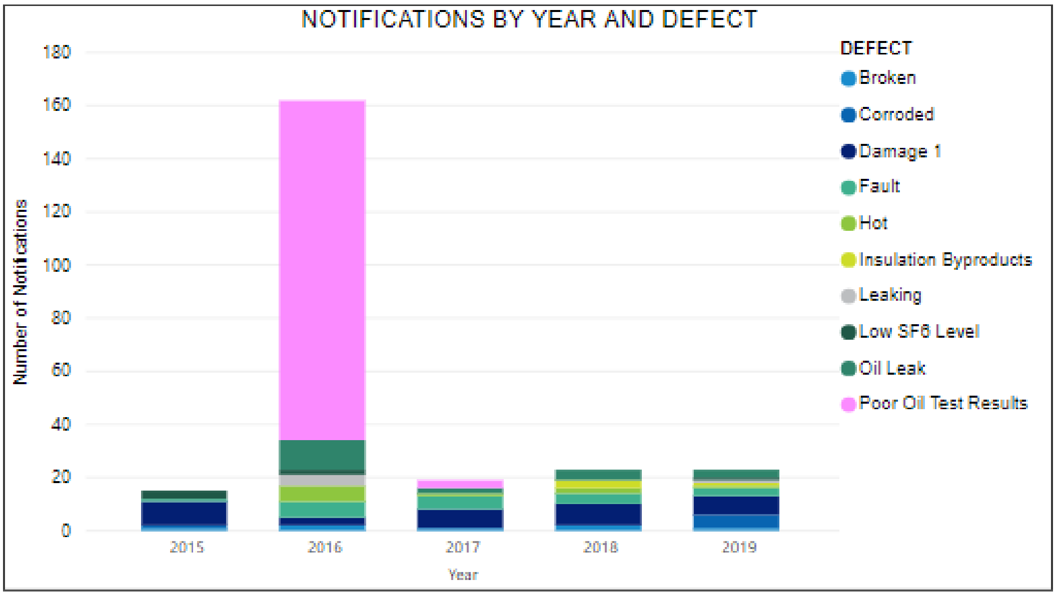

Figure 19 – Number of CT ZA Notifications vs Defect 2015 – 2019 (top 10)

Figure 20 provides the Number of CT ZA Notifications Vs Object Part for the period 2015 – 2019. Oil as the insulation medium was the key object part affected which contributed to approximately 79.5% of CT ZA notifications in 2016.

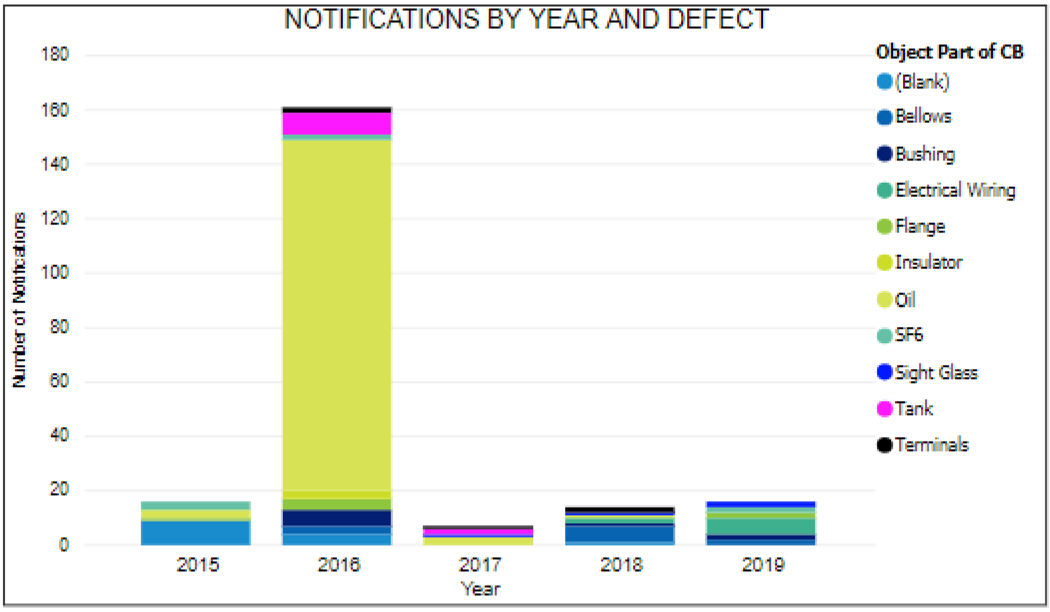

Figure 20 – Number of CT ZA Notifications vs Object Part affected 2015 – 2019 (top 10)

3.6.2 Voltage Transformers (MVT, CVT, CVD)

Figure 21 provides the Number of ZA Notifications per voltage transformer by voltage during the period 2015 – 2019. Approximately 50% of the VT notifications in the year 2019 were due to 220kV ,330kV & 500kV CVTs.

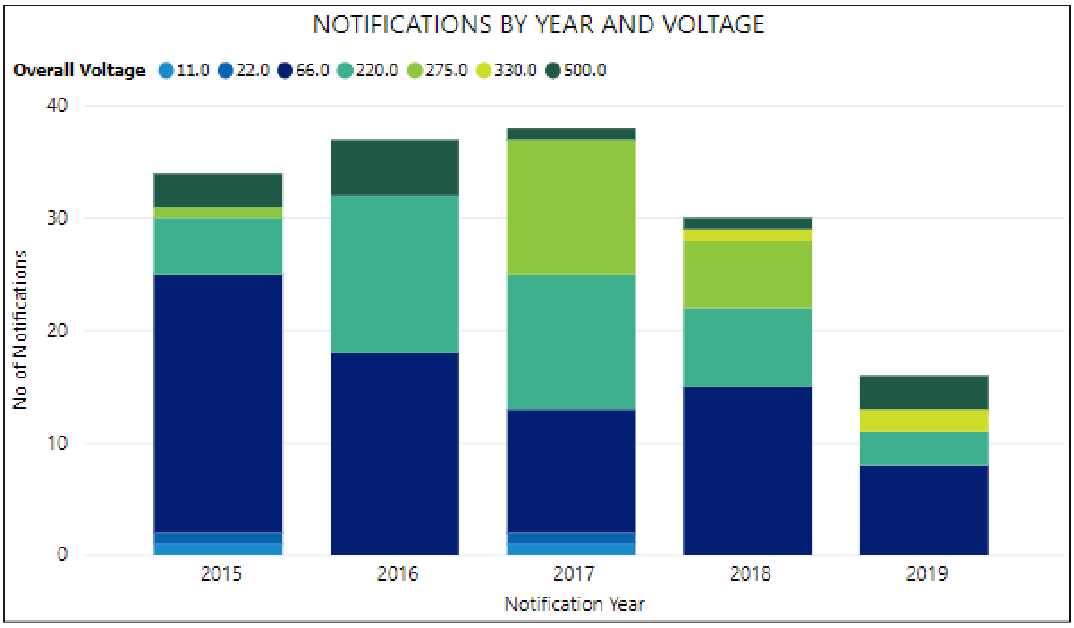

Figure 21 – Number of ZA Notifications per voltage transformer vs Voltage 2015 – 2019

Figure 22 provides the Number of ZA Notifications per VT manufacturer model during the period 2015 – 2019. [C-I-C]) had been common VT types which had the highest number of ZA notifications throughout the period 2015-2019.

[C-I-C]

Figure 22 – Number of ZA Notifications per VT Manufacturer 2015 – 2019 (top 10)

Figure 23 provides the Number of VT ZA Notifications Vs Defect type during the period 2015 – 2019. Oil leaks contributed to 61.5% of VT ZA notifications in 2019.

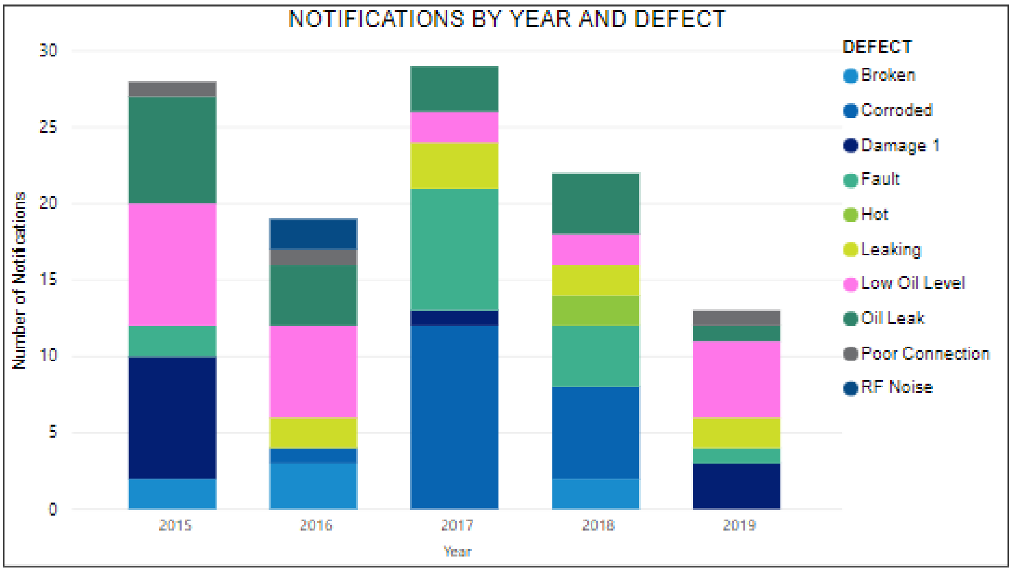

Figure 23 – Number of VT ZA Notifications vs Defect 2015 – 2019 (top 10)

Figure 24 provides the Number of VT ZA Notifications Vs Object Part for the period 2015 – 2019. Issues in Secondary systems contributed to 37.1% of total ZA notifications during the period 2015-2019. Other key affected object parts are Insulator bushings (18.9%), sight glass (12.9%), Oil insulation medium (12.9%) and other (18.2%) during the last 5-year period.

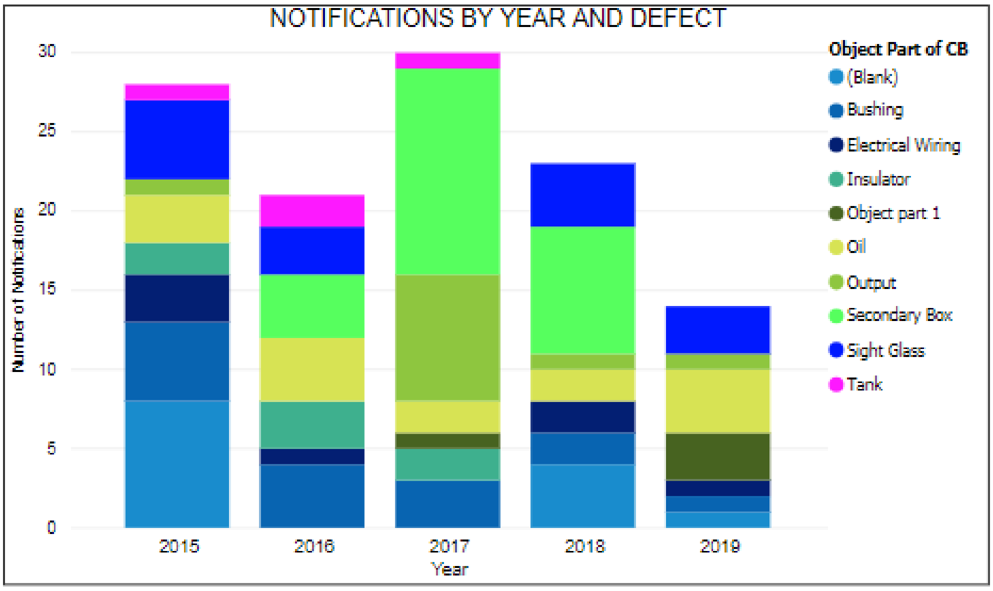

Figure 24 – Number of VT ZA Notifications vs Object Part affected 2015 – 2019 (top 10)

3.6.3 Urgent Replacements and Major Asset Failures

A number of major defects and failures associated with instrument transformers during the period from 2008 - 2019 which require complete replacement or replacement of a major component is shown in Appendix 1. Major failures or defects can result in extended duration outages and deplete critical spares holding especially the older instrument transformers which are technically obsolete. Alternatively, newer instrument transformer types have to be used with modified adapter mounting and also match secondary specification for old legacy types.

3.6.3.1. CAMS Alarms from CVTs requiring urgent replacements:

A continuous monitoring system called the CVT Asset Monitoring System (CAMS) has been developed to allow the early stages of deterioration of CVTs in service at terminal stations. When unexplained voltage variations in the output of CVTs are encountered the units are further investigated and removed from service before runaway failure occurs.

Several CVTs had to be urgently replaced following CAMS alarms in the last 5 years due to developing problems in them at several sites and averted possible catastrophic failures of porcelain housed CVTs at the following locations:

[C-I-C]
[C-I-C]
[C-I-C]

3.6.4 Catastrophic Failures

Catastrophic failures of instrument transformers can have serious health and safety risk to personal and result in damage to adjacent plant and equipment in the station due to dangerous fragments of porcelain projectiles associated with oil fires. There has been a number of catastrophic failures over the last 20 years.

More recently a catastrophic failure with fire and collateral damage occurred at RTS during the rebuild construction phase in 2016. The CT type was a 220kV [C-I-C]. This was a very significant event and reminded everyone the severe consequences of such an event.

The most recent CVT catastrophic failures occurred in 2009, where a [C-I-C] 500kV CVT and [C-I-C] 220kV CVT both failed in that year.

Targeted CT and CVT replacement programs as well as extending the use of CAMS system following earlier CVT failures has been able to avert possible catastrophic failures due to detective and predictive methods adopted using life cycle management techniques adopted as mentioned in section 3.6.3.1 to detect evident failures of CVTs. Subsequent investigation confirmed that a catastrophic failure of the 500kV [C-I-C] and 220kV [C-I-C], detected in 2017/18, would have occurred without the timely urgent removal from service.

Poor oil DGA results indicate signs of partial discharge activity taking place inside the instrument transformer and they were replaced within a short period of time averting catastrophic failure. However, oil sampling is not possible in all types and not possible to predict hidden failures. (ex: [C-I-C] and certain [C-I-C] types)

3.6.4.1. [C-I-C] CT

[C-I-C] CTs of various voltage ratings have a generic construction weakness related to the paper insulation system. This has been confirmed by strip-down tests by Ausnet Services and by other utilities in NSW. There have been significant [C-I-C] replacement programs in the past 15 years, with the all 500 kV and 330KV CT replaced and majority of 220 kV [C-I-C] CTs replaced on oil DGA analysis condition.

An Australian C'igre CT study reported replacement of several 72kV [C-I-C] CTs in NSW based on DGA results. AusNet Services 66 kV [C-I-C] CT DGA results have also shown signs of degradation of insulation.

3.6.5 [C-I-C] 500kV CT

[C-I-C] 500kV CT have a known deterioration /relaxing of the paper tension that's leads to arcing at the capacitive tap connection inside the CT as well as gradual thermal degradation. These are relatively large oil filled porcelain housed CT that's could fail catastrophically with significant collateral damage and fire. In the past 15 years, a few have urgently been removed due to presence of arcing DGA gases, and there have been significant replacement programs on prioritised basis.

3.6.5.1. 66kV [C-I-C] CVT:

Powercor experienced a catastrophic failure of a 66kV [C-I-C] CVT in 2014.

4 Other Issues

4.1 PCB in Oil-paper insulated instrument transformers

Older oil filled instrument transformers such as [C-I-C] types have been found to contain Polychlorinated Biphenyls (PCBs) in oil which requires special handling procedures to be followed during their life cycle management due to health and safety and environment concerns if contaminated with environment.

4.2 Asbestos in Instrument Transformers

Black Asbestos containing material is found only in some older instrument transformer electrical backing boards in older stations. However, no asbestos containing material was found in secondary terminal boards.

Asbestos material has the potential to cause harm to the safety and health of people, equipment, or the environment. Certain control measures have to be adopted when it is required to modify or removing asbestos as per HSP-05-05-1 guideline.

4.3 Technical Obsolescence /Spares Management

Manufacturers generally cease to formally support identical spare instrument transformers for older types beyond 30 years. Although serviceability can be improved midway through asset operational life, by increasing the level of spares held in stores just before the OEM ceases manufacture stores holding will deplete to the point that salvaging older instrument transformers in good condition become the only means of supporting a fleet of CTs or VTs.

[C-I-C] types are now technically obsolete. They have inherent design issues and safety concerns when the condition becomes poor. They are replaced with fail safe modern CTs or VTs with polymeric housings during station augmentation and asset replacement programs.

4.4 CVT online health monitoring

CVT online monitoring is available through a 'CAMS' system built into the network SCADA system and providing alarms when output varies beyond normal levels, in excess of 98% of CVT's are monitored and the system has proved effective in detecting CVT about to fail and avoiding catastrophic failures since it was introduced in early 2000's.

CVD introduced between 2000 to 2015 for AEMO quality of supply monitoring are not monitored by the CAMS system as they do not feed into SCADA. There has been some early CVD under investigation removed due to low voltage output. There is growing need to investigate an online CAMS system for CVD's

4.5 Dead tank CB

At 66kV and 220kV voltages the preferred CB type, for safety and economic reasons, is dead tank type with integral low voltage type CT's. This removes the need for outdoor post the CT with HV insulation. As such an integrated approach to CT and CB replacement is required.

5 Risk and Option Analysis

5.1.1 Current Transformers

The key drivers of this program are managing safety risk, supply risk and collateral damage risk.

Table 4 is a current assessment of the risk based upon the condition of the assets (C1- C5) and the monetised consequence of failure (criticality bands 1 – 5). CT Replacements planned during the current TRR period have been excluded from the Table.

The 128 current transformer assets in the high-risk area (Red zone) of the matrix mainly correspond to very poor condition (C5) 66kV [C-I-C] types and 500kV [C-I-C] types ,220kV [C-I-C] types and poor condition (C4) mainly [C-I-C] which are expected to be phased out during the 2022-2027 TRR period.

Current transformers that are under replacement during the current period have been excluded from the risk matrix.

Criticality Band	C1	C2	C3	C4	C5
5	166	49	71	25	44
4	40	9	13	3	10
3	49	33	29	14	12
2	52	34	107	82	31
1	322	108	122	93	3

Table 4- Current Transformer Risk Assessment

Excluding the ones identified to be replaced under station rebuilds during 2022-2027, following asset replacements are identified to be carried out under TRR 2022-27 period:

- Replace 12 off identified high risk C5 and C4 condition Current Transformer types: 500 kV [C-I-C] 06/550/5 types and 03 off 220kV [C-I-C] types
- Replace 27 identified high risk C5 and C4 condition Current Transformer types: 66kV [C-I-C] types (excluding 12 off associated CTs with poor condition LTCBs to be replaced with DTCBs - refer AMS 10-54)

5.1.2 Voltage Transformers (MVT, CVT)

The key drivers of this program are managing safety risk, supply risk and collateral damage risk.

Table 5 is a current assessment of the risk based upon the condition of the assets (C1- C5) and the monetised consequence of failure (criticality bands 1 – 5). VT Replacements planned during the current TRR period have been excluded from the Table.

The 96 voltage transformer assets in the high-risk area (Red zone) of the matrix mainly correspond to very poor condition (C5) and poor condition (C4) CVTs mainly 66kV and below [C-I-C].

Voltage transformers that are under replacement during the current period have been excluded from the risk matrix.

Criticality Band	C1	C2	C3	C4	C5
5	40	57	32	33	5
4	131	84	43	25	8
3	52	25	70	91	25
2	14	28	20	48	0
1	276	91	32	19	12

Table 5- Voltage Transformer Risk Assessment

Excluding the ones identified to be replaced under station rebuilds during 2022-2027 and VCU units associated with Transformers and Circuit breakers, following asset replacements are identified to be carried out under TRR 2022-27 period under asset replacement program:

- Replace 5 identified high risk C5 condition CVTs and MVT types: [C-I-C] types
- Replace identified high risk C4 condition 6 off 220kV [C-I-C] CVTs and 16 off 66kV [C-I-C] CVTs and MVTs

6 Asset Strategies

6.1 Current Transformers

6.1.1 New Installations

- Install dead tank circuit breakers with integral CT's where possible up to 220kV operating voltage level
- Where associated CB is not being replaced or a live tank type, install polymer housed oil –paper insulated outdoor current transformers to latest specification for 66 to 330kV, and polymer housed SF6 gas insulated outdoor current transformer for 500kV
- Install high quality epoxy cast resin current transformers for operating voltages at and below 22kV.

6.1.2 Inspection

- Continue visual inspection during regular station inspections
- Continue annual non-invasive thermal and RF scanning

6.1.3 Maintenance

- Continue condition monitoring through regular oil sampling and DGA analysis, as per PGI 02-01-02.
- Continue to establish enhanced sampling oil DGA sampling regime for approaching end of life CT's
- Establish improved tracking of overdue oil DGA sampling
- Continue to monitor closely trends in the 10 to 20 years old ABB polymer housed CTs

6.1.4 Replacement

- Replace 12 off identified high risk C5 and C4 condition Current Transformer types: 500 kV [C-I-C] 06/550/5 types and 03 off 220kV [C-I-C] types
- Replace 27 identified high risk C5 and C4 condition Current Transformer types: 66kV [C-I-C] types

6.2 Voltage Transformers

6.2.1.1. New Installations

- Install polymer housed oil –paper insulated outdoor inductive voltage transformers to latest specification up to 66kV operating voltage
- Install polymer housed oil –paper insulated outdoor capacitive voltage transformers to latest specification for higher than 66kV operating voltage
- At 22kV and below, install high quality epoxy cast resin voltage transformers
- Install CVT asset monitoring system (CAMs) on all CVTs installed in the transmission system

6.2.1.2. Inspection

- Continue visual inspection during regular station inspections
- Continue annual non-invasive thermal and RF scanning

6.2.1.3. Maintenance

- Continue condition monitoring through regular oil sampling and DGA analysis of MVT

6.2.1.4. Condition Monitoring

- Maintain CAMS to provide 100% functional coverage for CVT
- Investigate and introduce CAMS for CVD (used for AEMO quality of supply monitoring)

6.2.1.5. Replacement

- Replace 5 identified high risk C5 condition CVTs and MVT types: [C-I-C] types
- Replace identified high risk C4 condition 6 off 220kV Tyree CVTs and 16 off 66kV [C-I-C] CVTs and MVTs