AMS 10-53 Capacitor Banks

2023-27 Transmission Revenue Reset

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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 terminal station capacitor banks.

The strategy covers the 59 regulated capacitor banks located in Terminal stations. The most common type being the 66kV 50 MVAr capacitor banks, that contribute to 36% of the capacitor bank population.

Most capacitor banks are in reasonable health and 86% of the total population are either in a "very good condition" (C1), "good condition" (C2) or "average condition" (C3). The remaining 14% of the total population are either in "poor condition" (C4) or "very poor condition" (C5).

Capacitor bank network criticality studies, combined with condition, has identified a few sites where risk warrants wholesale replacement. Most of these are part of current period station redevelopment, leaving only a smaller condition based reactive replacement of capacitor cans and series reactors, is recommended for the 2022-27 regulatory period.

Proactive management of terminal station capacitor banks condition-based maintenance and replacement practice is required to ensure that stakeholder expectations of cost, reliability, safety and environmental performance are met. The summary of proposed asset strategies is listed below.

1.1 Asset Strategies

1.1.1 New Assets

- Continue to purchase capacitor banks to the latest specification with capacitors internally fused and capacitor bank detuned against harmonic resonance.

1.1.2 Inspection / maintenance / condition monitoring

- Continue maintaining capacitor banks in accordance with PGI 02-01-02.
- Monitor and review settings of capacitor bank neutral unbalance, auto operation in order to minimise nuisance tripping and mal operations
- Continue with annual thermo-vision scans of all capacitor banks (as part of station scan and as per SMI 67-20-01).

1.1.3 Spares Holding

- Maintain strategic spares holding of capacitor cans and series reactors as per spare holding policies

1.1.4 Replacement

- Replace poor condition cans as required

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 capacitor banks installed in terminal stations in AusNet Services' Victorian 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 the regulated asset base 22 kV, 66kV, 220kV and 275kV capacitor banks located in terminal stations.

The key components of the capacitor banks covered by this strategy are capacitor cans and series inrush reactors.

The associated capacitor bank circuit breakers and neutral and balance current transformers, and cap banks included as components of an SVC are covered under other strategies;

- AMS 10-54 Circuit Breakers;
- AMS 10-64 Instrument Transformers
- AMS 10-71 Static VAR Compensator

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.

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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

Capacitor banks in terminal stations provide voltage support by compensating reactive power and improved stability to the transmission, sub transmission networks. They also assist in minimising system power losses and maximising utilisation of transformers and HV lines.

When a capacitor bank fails, the VAR (reactive power) support provided at terminal station is lost, and this gives rise to increased system losses and restricted ratings mainly on lines and station transformers particularly during heavy demand periods. It also lowers the effective station loading capability.

3.2 Asset Population

AusNet Services has a total of 59 capacitor banks in service installed in AusNet services in the electricity transmission network as reported in the 2019 RIN. The population of capacitor banks by bank nominal rating is given in figure 1.

66kV and 220kV capacitor banks contribute to 89% of the total population mainly consisting of 66kV (70%), 220kV (19%) and other voltages (11%).

Figure 2 below provides the capacitor bank rating range by voltage and most common average bank size is 50MVAr at 66kV. Capacitor bank ratings range from 5.4 MVAr to 158.4 MVAr.

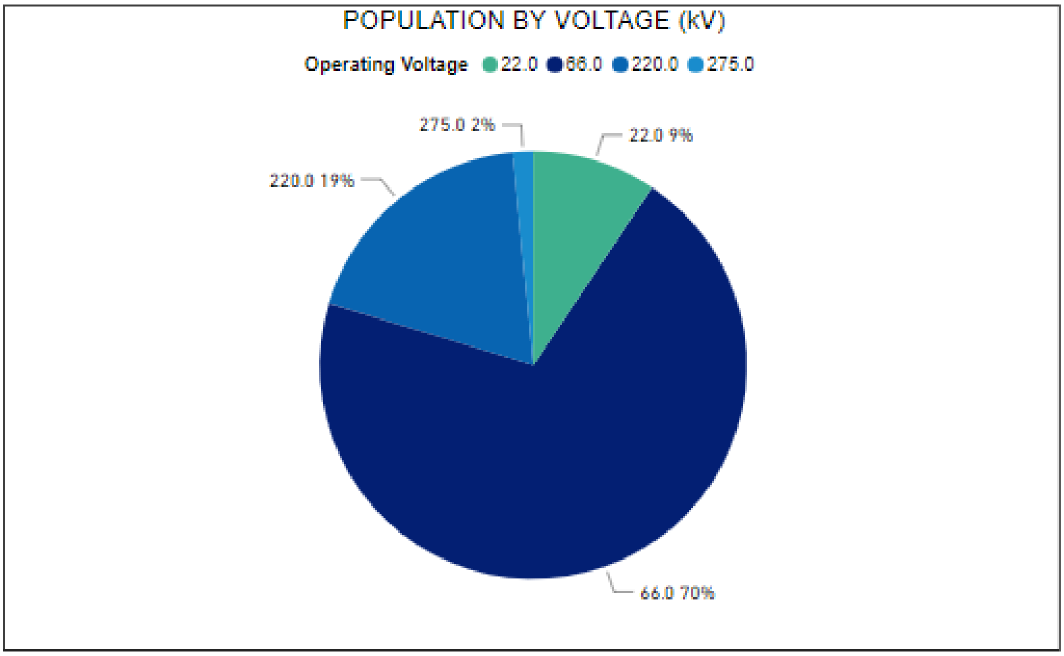

Figure 1 – Population of capacitor banks by operating Voltage (kV)

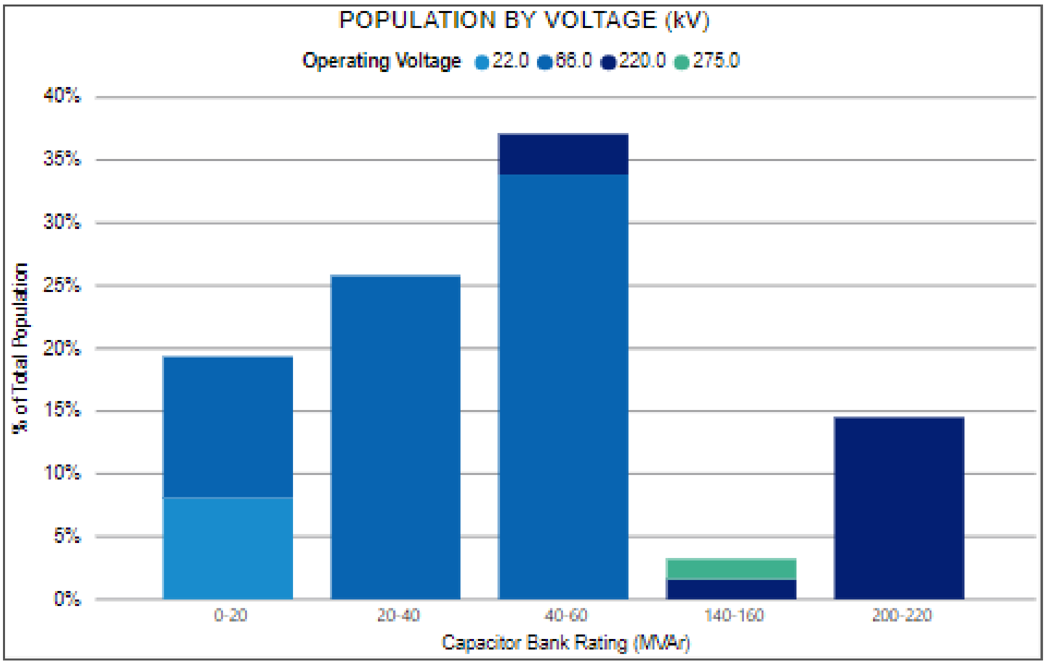

Figure 2 – Population of capacitor banks by nominal rating in MVAr

Figure 3 below provides the capacitor banks by the Manufacturer and [C-I-C] is the predominant manufacturer terminal station capacitor banks which contribute to 85.1% of the total population of capacitator banks across the network.

[C-I-C]

Figure 3 – Population of capacitor banks by Can Manufacturer

Most capacitor banks are switched by reactive-demand or time-based controllers to provide necessary reactive compensation at times of peak loading. With the high utilisation of transmission network assets over the last decade, the number of switching operations, duration of capacitor bank operating periods and duty has been significant.

3.3 Asset Age Profile

Figure 4 below provides the age profile of capacitor banks by operating voltage. Average age of capacitor banks is 25 years with oldest being 43 years at KGTS 22kV capacitor bank.

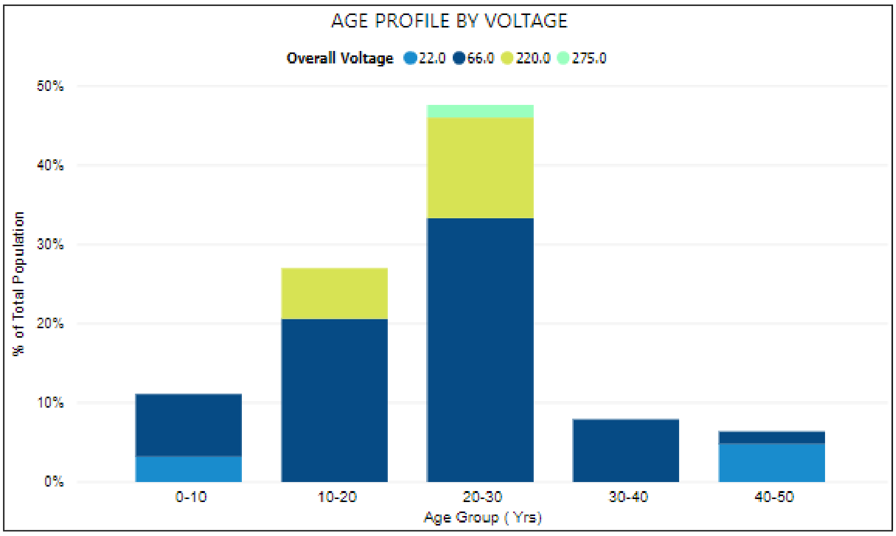

Figure 4 – Age Profile of Capacitor banks by Operating Voltage (kV)

Figure 5 below provides the capacitor banks series reactor age vs operating voltage. Approximately 2.9% of the population are 40-50 years old and installed on 22kV capacitor banks. Approximately 13.4% of the total population of series reactors are aged between 30 - 40-year group and they are installed on 66kV capacitor banks. All the other series reactors are below 30 years of age. They are all Trench Reactors of various reactance and current ratings.

Design service life of outdoor capacitor bank series reactors is about 30 years. There are no effective testing methods available other than visual inspection that provide some guidance about physical deterioration of in-service reactors before its failure. Several failures occurred, and deterioration observed in older 66kV capacitor banks in the last 5 years. Failure of a series reactor make the cap bank in operable and reduces the reliability and availability of capacitor banks for reactive support. Currently a 66kV capacitor bank series reactor replacement project is underway to replace older deteriorated reactors at various stations.

Capacitor cans deteriorate with utilisation and voltage surges and they are replaced much earlier than the series reactors during planned and unplanned maintenance work and easy to replace at a low cost in comparison to series reactors where replacement usually unplanned and aged based.

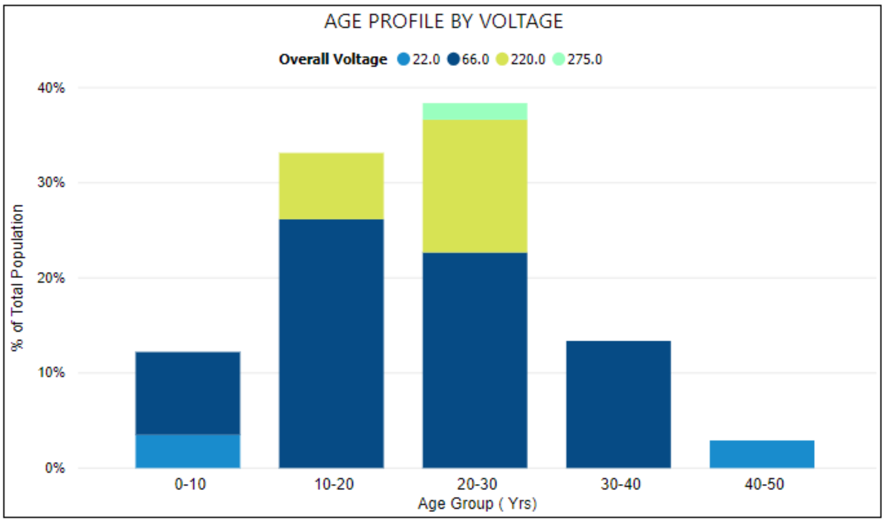

Figure 5 – Population of Series Reactors by Voltage

3.4 Asset Condition

Table 1 provides the condition assessment criteria of Capacitor banks in terminal stations.

Table 1: Condition Assessment Criteria

Condition Score	Condition Description	Summary of details of condition score	Remaining Service Potential
C1	Very Good	These Capacitor banks are generally less than 10 yrs old and in good operating condition with no past history of defects or failures. Manufacturer support and spares are readily available for routine maintenance. Routine maintenance and continued condition monitoring is recommended.	95%
C2	Good	This category includes capacitor banks which are in better than average condition . They may not have developed actual faults but developing minor issues due to connection , secondary or other unknown causes. They do not require intervention between scheduled maintenance nor do they show any trends of serious deterioration in condition or performance. Manufacturer support and spares are available.	70%
C3	Average	This category includes capacitor banks which are with an average condition (Some cap banks may had capacitor cans , reactors replaced and by doing so condition had improved to average level.) These units particularly require increased maintenance. Spare reactors and cans are being used to replace cracked reactors and defective cans.	45%
C4	Poor	This category includes capacitor banks with old capacitor cans and reactors which are in worse than average condition. They may have developed an increasing number of defects due to frequent fuse blowing ,unbalance protection trips and other secondary issues which require frequent intervention. Manufacturer support is not available for older ASEA capacitor cans and reactors. In situ repair/component repelcement are becoming the most practical solution.	25%
C5	Very Poor	This category includes capacitor banks which are typically maintenance intensive and have history of recurrent failures resulting in frequent component replacements. The defects develop within the maintenance inspections is a major concern.	15%

Condition profile of Capacitor banks is shown in Figure 6.

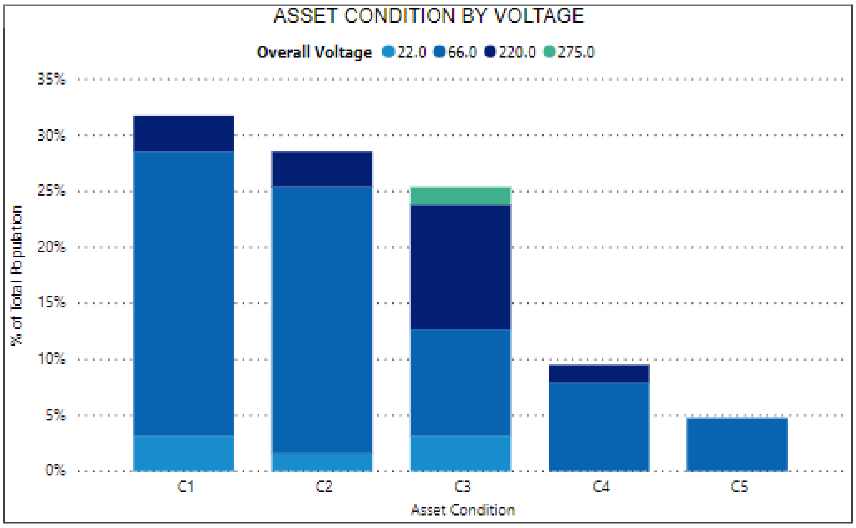

Figure 6 – Condition Profile of Capacitor banks vs Voltage

Approximately 9.5% and 4.7% of capacitor banks in terminal stations are either in C4 and C5 asset condition respectively. These capacitor banks include the 66kV (12.7%) and 220kV (1.59%) of total population of capacitor banks.

3.5 Asset Criticality

Asset Criticality of a single terminal station capacitor bank failure is lower than other assets types due to lower direct system impact or direct community impact, safety impact, and collateral damage impact. Malfunction or non-functioning of a capacitor bank affects mainly customer power quality and increase in power losses of the network. A few capacitor banks mentioned below become important during certain time of the year to maintain the voltage quality of customers but typically their average criticality level is low. Capacitor bank system criticality is determined by Network Planners, and often re-assessed as part of detailed system studies for station major replacement and redevelopment projects.

One qualitative measure of criticality is the frequency of use of the capacitor bank. Some cap banks are used for daily voltage support and others seasonal peak loading and post contingent events. Using the banding below, a one measure of criticality is shown in Table 2.

Table 2: Interpretation of Relative Base Criticality

Relative Base Criticality	Criticality Banding	Definition
Very low	1	< 10 energisations per year, rarely used
Low	2	10-30 energisations per year, close seasonal use
Medium	3	30-100 energisations per year, seasonal use
High	4	100-300 energisations per year, regularly used
Very high	5	>300 energisations per year, effectively daily use

The Figure 7 shows the Relative asset criticality vs Operating voltage. Approximately 22.8% of the capacitor banks can be categorised as either high (17.5%) or very high criticality(5.3%) out of which 21.1% are 66kV capacitor banks and approximately 5.3% are categorised as very high criticality.

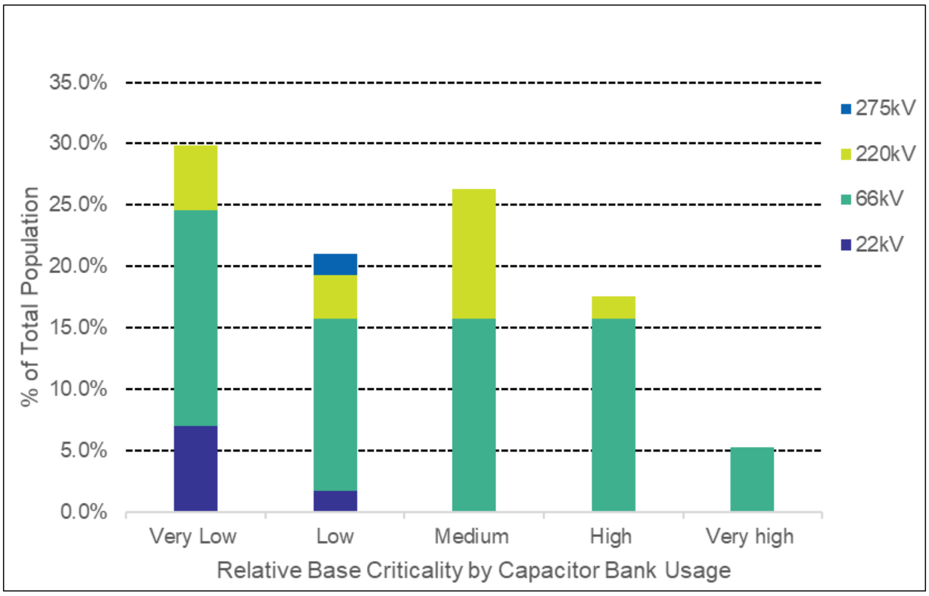

Figure 7 – Relative base criticality Vs Capacitor Bank Operating voltage

The most common type of capacitor bank failure is failure of a capacitor can or cans or rarely a series reactor failure. This causes the capacitor bank to be out of service till the cans are replaced as protection systems are unable to cope with the imbalance in phase currents. During this time the voltage support provided by a capacitor bank would not be available and as a result power factor will not be optimised and thus electrical losses will be higher and rare occasions of capacity constraints in a single capacitor bank stations.

3.6 Asset Performance

AusNet Services routinely analyses the root cause of unplanned work undertaken on capacitor banks and investigates all major failures and tracks their effects on reliability and power quality to the customers.

3.6.1 Corrective Maintenance

All terminal station capacitor banks are subjected to routine maintenance in accordance with PGI 02-01-02 and relevant standard maintenance instructions (SMI).

Figure 8 provides the Number of ZA Notifications per capacitor bank by operating voltage during the period 2015 – 2019.It is observed approximately 64.8% of the total ZA notifications had been raised on 66kV capacitor banks during the 2015-2019 period, note that it had declined over the period.

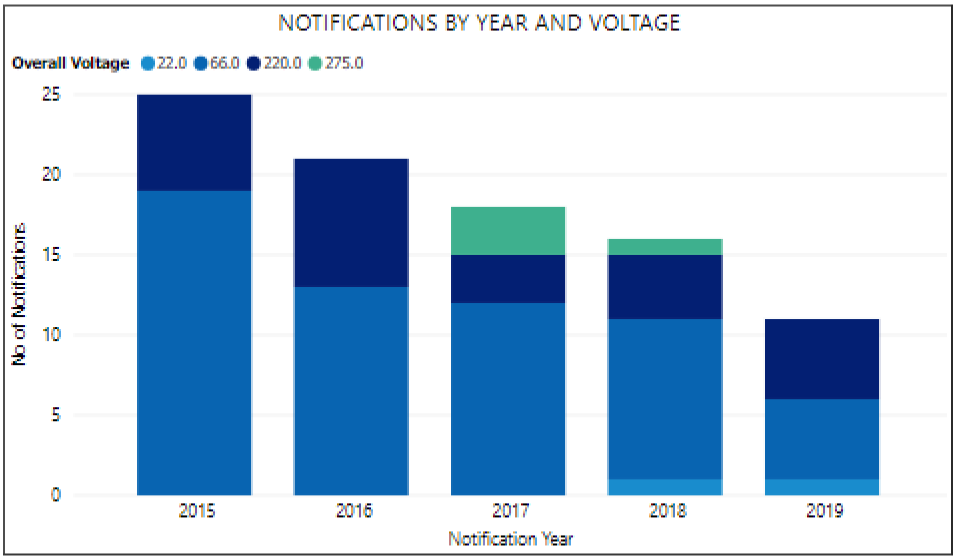

Figure 8 – Number of ZA Notifications per capacitor bank vs Voltage 2015 – 2019

Figure 9 provide the worst performing capacitor banks in terminal stations. 66kV HTS, ERTS, SVTS, WMTS & TTS No2 capacitor banks and TTS 220kV capacitor bank had performed poorly during the period 2015-2019. Worst performed RTS 66kV capacitor banks have been rebuild under Richmond Rebuild Project in 2019.

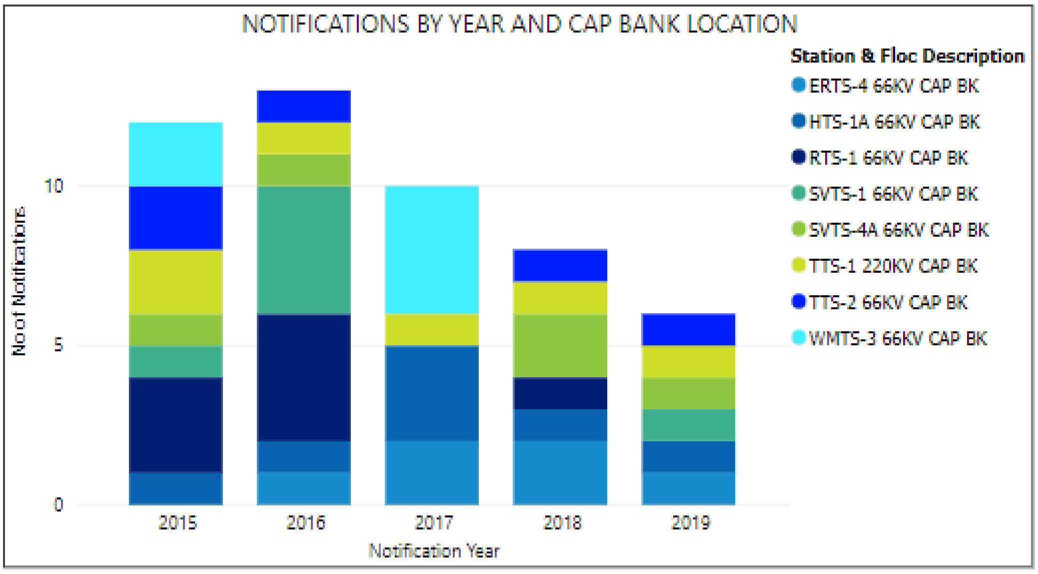

Figure 9 – Number of ZA Notifications Vs Capacitor Bank 2015 – 2019 (worst Top 5 by notifications)

Figure 10 provides the Number of capacitor bank ZA Notifications Vs Defect type during the period 2015 – 2019.
It is noted that approximately 79.2% of the ZA notifications are due to hot connections (20.8%), and poor connections (20.8%) and capacitor bank phase unbalance (20.8%) and can failures (16.8%) during the period 2015-2019.

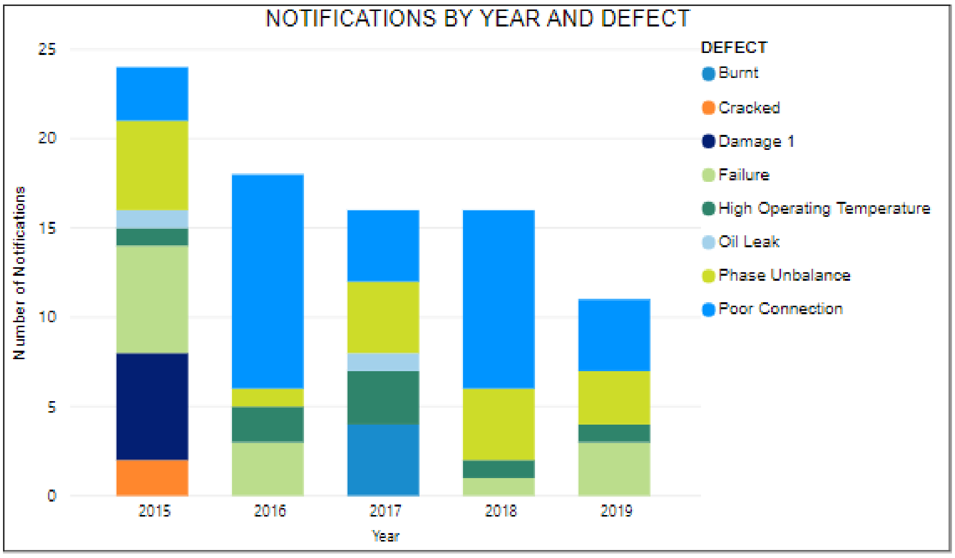

Figure 10 – Number of ZA Notifications per capacitor bank vs Defect 2015 – 2019

Figure 11 provides the Number of capacitor bank ZA notifications Vs Object Part for the period 2015 – 2019.
It is noted that primary connections (42.4%) and capacitor can failures (31.8%) were the key object parts affected that constituted to 74.1% of the total ZA notifications during the period 2015-2019. Series reactors caused 2.4% of the failures.

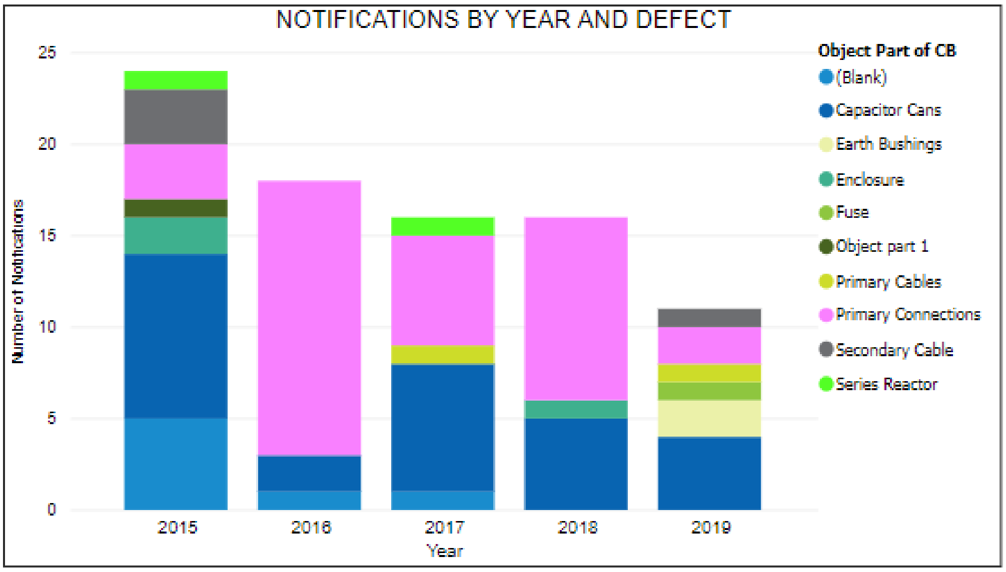

Figure 11 – Number of ZA Notifications per capacitor bank vs Object part affected 2015 – 2019

4 Other Issues

4.1 Monitoring Capacitor Cans

Capacitor cans deteriorate with utilisation and voltage surges. This causes random out-of-balance alarms and, in some cases, tripping of the capacitor bank. In either event, individual faulty cans are replaced and measurement of capacitance and some rebalancing between phases is required.

It was also found another factor of increased capacitor can failures is due to defective circuit breakers restriking during switching the capacitor banks, (e.g. ,220kV RWTS No 2 capacitor bank, 220kV TTS No 1 capacitor bank) and can cause very significant cascaded failures of capacitor cans. Over half a single-phase bank has failed in the past. Spares holding does not account for this type of significant failure mode, resulting in months of downtime until cans can be replaced.

Prior to the event, it is difficult to detect or prevent these failures without substantial investment (in routine capacitance testing, for example) or by over-design of the capacitor units. Corrective action is needed when capacitor banks trip on unbalance (normally due to the failure of packets within cans). Corrective work is sometimes needed due to flashovers caused by birds or small animals.

4.2 Technical obsolescence of Key Components

Capacitor banks with older [C-I-C] Cans are becoming technically obsolete and the new [C-I-C] replacement cans have dimensional differences to the OEM capacitor cans. This requires cap bank structure modifications when retrofitting to accommodate the newer types which involve a retrofitting a complete phase module in some cases.

4.3 Detuning Reactors

Detuning/ Inrush reactors are typically dry type reactor with a multiple layer winding each embedded inn epoxy insulation. There is very limited testing or ability to truly condition assess a dry type reactor.

There have been several rector failures, which result in reportable fires in the last 10 years. These have all occurred during energisation. The entire fleet of the type that failed have been replaced.

4.4 Frequency of Use

The large variability in utilisation of Capacitor Banks, from rarely energised to more than daily use, can results in different reliability and expected useful life across similar assets.

5 Risk and Option Analysis

The key drivers of this program are capacity constraints, network stability, supply power quality, and network reliability provided by capacitor banks. Figure 12 show below the capacitor bank semi quantitative risk assessment based on capacitor bank usage.

Criticality Band	C1	C2	C3	C4	C5
5	0	1	2	0	0
4	0	4	3	2	2
3	5	8	4	1	0
2	6	2	3	0	0
1	9	4	2	3	1

Figure 12: Terminal station Capacitor Bank Risk Assessment

Majority of Terminal Station Capacitor banks are generally in acceptable condition. The majority of the higher risk red zone capacitor banks are being replaced in the current TRR period as part of major projects. Analysis of the remaining red zone capacitor bank, namely the TTS No 2 66kV cap bank, suggests replacement towards end of TRR period 2022- 2027 or in the following TRR period 2028 to 2033.

For the remainder, most economic option is to continue to monitor and hold adequate spares to attend can failures and by carrying out smaller condition-based component replacement. The ongoing performance of the TTS No 2 66kV cap bank will be closely monitored.

6 Asset Strategies

6.1 New Assets

- Continue to purchase capacitor banks to the latest specification with capacitors internally fused and capacitor bank detuned against harmonic resonance.

6.2 Inspection / maintenance / condition monitoring

- Continue maintaining capacitor banks in accordance with PGI 02-01-02.
- Monitor and review settings of capacitor bank neutral unbalance, auto operation in order to minimise nuisance tripping and mal operations
- Continue to monitor can failure rate
- Continue with annual thermo-vision scans of all capacitor banks (as part of station scan and as per SMI 67-20-01).

6.3 Spares Holding

- Maintain strategic spares holding of capacitor cans and series reactors as per spare holding policies

6.4 Replacement

- Replace poor condition cans as required

Appendix 1 – Terminal Station Capacitor Bank Typical Defects / Failures 2015- 2019

[C-I-C]

[C-I-C]