Circuit Breakers

AMS – Electricity Distribution Network

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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 distribution network. The purpose of this strategy is to outline the inspection, maintenance, replacement and monitoring activities identified for economic life cycle management of zone substation circuit breakers.

The strategy covers 982 circuit breakers and step switches installed in zone substations. Approximately 39.4% of the circuit breakers are older bulk oil circuit breakers (23.1%) and minimum oil circuit breakers (16.3%). The remaining 60.6% of the CB population consists of vacuum (50.5%) and SF6 (10.1%) circuit breakers. SF6 CBs are mainly installed in 66kV network while vacuum circuit breakers are installed in 22kV indoor switchboards.

Condition assessment shows approximately 66.7% of the total CB population are either in a "Very Good" condition (C1), "Good" condition (C2) or "Average" condition (C3). The remaining 33.3% of the total CB population are either in "Poor" condition (C4, 13.0%) or "Very Poor" condition (C5, 20.3%).

The consequence of a failure was assessed based on safety impact, environment and collateral damage and community impact due to outages. Using the condition assessment and consequence criticality, a quantitative risk assessment for circuit breakers was performed. This has established an economically sound replacement program for high risk circuit breakers during the period 2022-26.

Proactive management of circuit breakers 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 Asset Strategies

1.1.1 New Assets

- Specify outdoor SF_6 insulated dead tank/ polymer insulator circuit breakers for replacement in 66 kV installations.
- Specify indoor metal clad /arc fault rated vacuum interrupter circuit breakers in indoor modular switchboards for 22 kV installations.

1.1.2 Condition Monitoring

- Continue visual checks of circuit breakers as part of the regular zone substation inspections.
- Continue annual non-invasive condition monitoring scans including the use of radio frequency interference, ultrasonic, infra-red thermal and UV corona camera testing.
- Continue to establish the bulk oil CB's SRBP bushing condition through an electrical testing program

1.1.3 Maintenance

- Continue scheduled preventative maintenance as per specific Standard Maintenance Instructions for each circuit breaker type.

1.1.4 Spares

- Maintain strategic spares holding of circuit breakers as per spare holding policies
- Continue to salvage best parts and complete assemblies of obsolete CB to achieve per spare holdings

1.1.5 Refurbishment

- Use bushing replacements to mitigate shorter term risk until bulk oil CB replacement is possible, for "Very Poor" condition bushings found during the electrical testing condition monitoring program

1.1.6 Replacement

- Replace 47 circuit breakers as part of station rebuild projects at various zone substations by 2025.
- Replace 32 circuit breakers at various zone substations under CB replacement program by 2025.

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 circuit breakers in AusNet Services' 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

This Asset Management Strategy applies to all outdoor and indoor type circuit breakers operating at 66kV, 22kV, 11kV and 6.6kV located in zone substations.

The following related assets are covered by other strategies;

Metal enclosed Switchboards where Indoor Circuit Breakers are installed refer to AMS-20 -56.

2.3 Asset Management Objectives

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

- Comply with legal and contractual obligations
- Maintain safety
- Be future ready
- Maintain network performance at the lowest sustainable cost, and
- Meet customer needs.

As stated in *AMS 20-01 Electricity Distribution Network Asset Management Strategy*, the electricity distribution network objectives are:

- Improve efficiency of network investments
- Maintain long-term network reliability
- Implement REFCL's within prescribed timeframes
- Reduce risks in highest bushfire risk areas
- Achieve top quartile operational efficiency
- Prepare for changing network usage

3 Asset Description

3.1 Asset Function

Circuit breakers are electrical switches that, in conjunction with protection relays and SCADA controls, operate automatically to interrupt the abnormal flow of electrical currents and protect people from injury and protect property and the electrical network equipment from damage.

Circuit breakers are also use to energise and de-energise lines, feeders, busses and electrical equipment such as transformers or capacitor banks to enable operation requirements, maintenance or augmentation works.

3.2 Asset Population

AusNet Services has a total of 982 circuit breakers (CB) installed in the electricity distribution network 1 (2017 RIN Category Analysis). Included in this number are capacitor bank CBs and step switches, neutral earth resistor (NER) by pass CBs and neutral earthing compensator (NEC) CBs. The number of circuit breakers increased by about 2.6% per annum since 2013. A summary of the distribution circuit breaker population by voltage class and technology type is shown in figure 1.

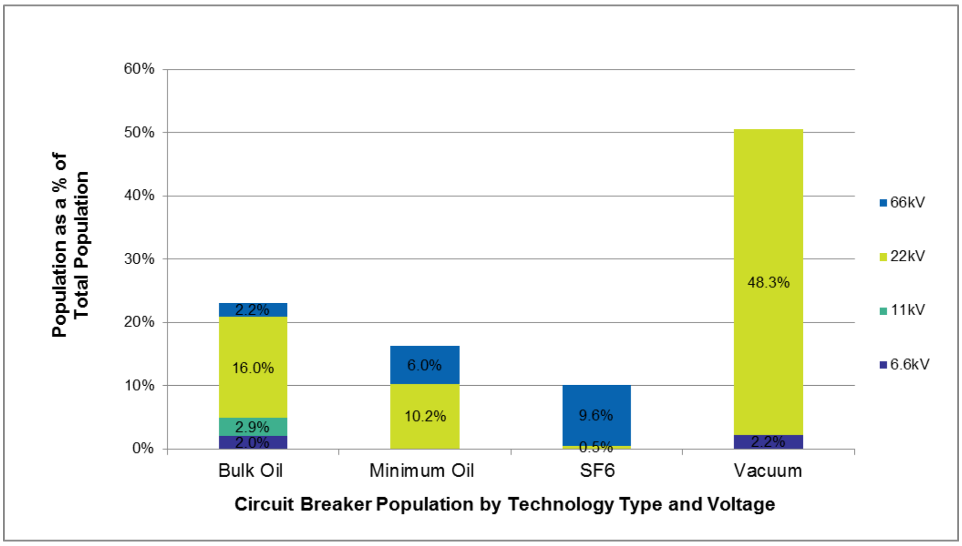

Figure 1 - Circuit Breaker population by Technology Type and Voltage

Approximately 92.8% of the circuit breakers in zone substations are located in 22kV and 66kV system where 99.6% of AusNet customers are connected to.

3.2.1 22kV Circuit Breakers

Approximately 16.0% of bulk oil circuit breakers and 10.2% of minimum oil circuit breakers of circuit breaker population are associated with 22kV distribution feeders. All the bulk oil Circuit breakers are outdoor and approximately 93% of the 22kV minimum oil circuit breakers are located indoors on the second generation switchboards. (Reference AMS 20- 56)

These Bulk oil and minimum oil circuit breaker types have lower limits of automatic switching operations before maintenance compared to modern vacuum circuit breakers. They are technically obsolete and no longer supported by the manufacturers. With the application of new technology in 22kV network; distribution feeder automation (DFA) and Rapid Earth Fault Current Limiter technology (REFCL), demands a very reliable and efficient circuit breaker with frequent auto reclosing. Life cycle management of these older CBs, especially 22kV minimum oil indoor circuit breakers is becoming difficult.

Figure 2 and 3 below provides the population of 22kV minimum oil and bulk oil circuit breakers by manufacturer/make. The population is dominated by only a few types. A current project is in progress to retrofit few [C.I.C] type indoor minimum oil circuit breakers during 2018 FY with modern vacuum indoor circuit breakers.

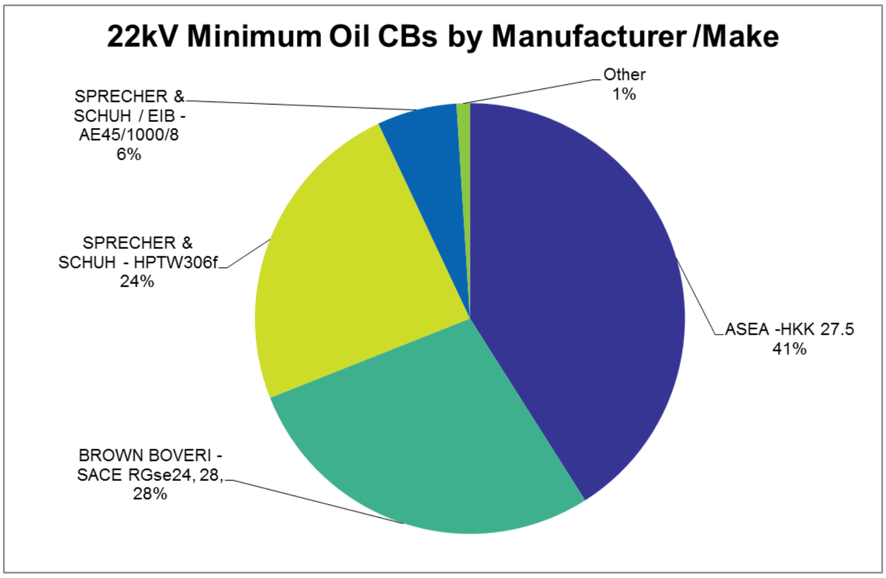

Figure 2 – 22kV Minimum Oil CBs by Manufacturer / Make

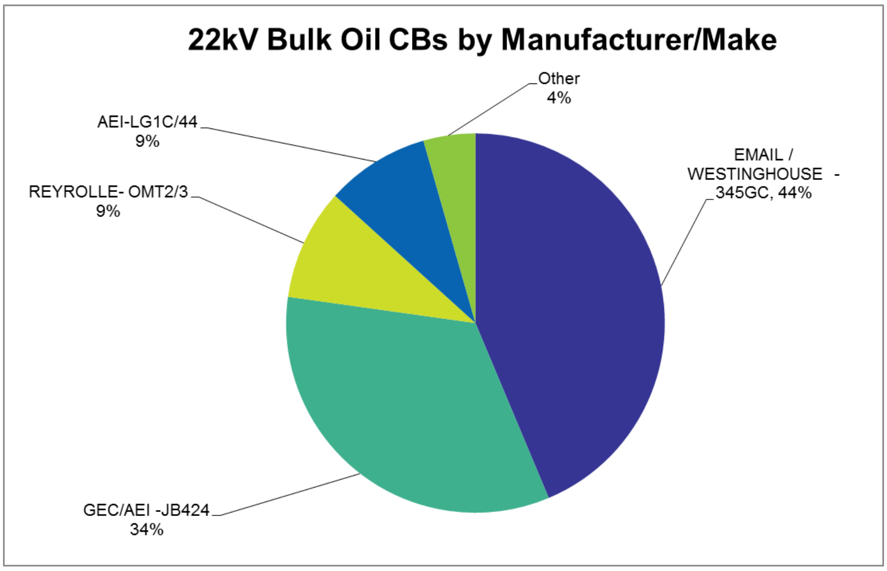

Figure 3– 22kV Bulk Oil CBs by Manufacturer / Make

3.2.2 66kV Circuit Breakers

Approximately 2.2% of bulk oil circuit breakers and approximately 6.0% of minimum oil circuit breakers are associated with 66kV distribution network. 66kV bulk oil and minimum oil circuit breakers types have lower limits of automatic switching operations before maintenance compared to modern SF6 circuit breakers. These circuit breakers are becoming technically obsolete and no longer supported by the manufacturers. Life cycle management of these older CBs, especially 66kV minimum oil circuit breakers is becoming difficult.

Figure 4 and 5 below provides the population of 66kV minimum oil and bulk oil circuit breakers by manufacturer/make. The populations are dominated by only a few types. A current project is in progress to replace the [C.I.C] population during the 2018 FY with SF6 insulated dead tank circuit breakers.

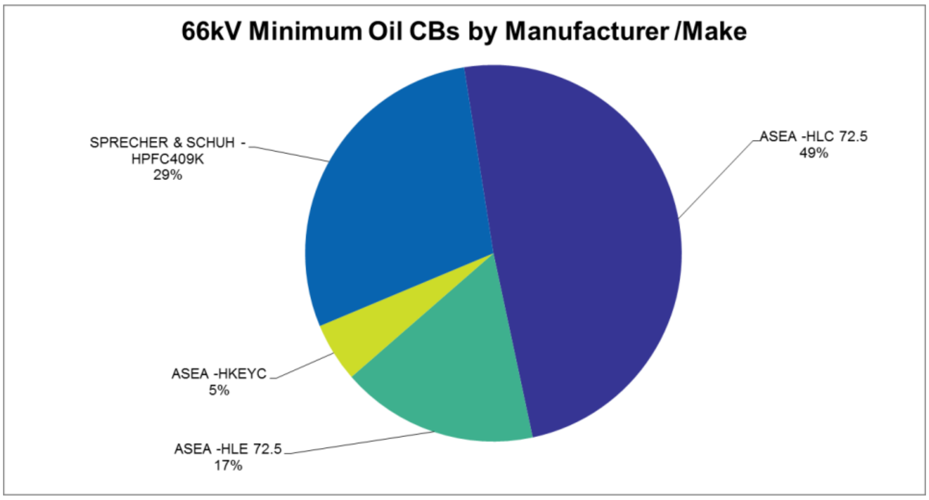

Figure 4 – 66kV Minimum Oil CBs by Manufacturer / Make

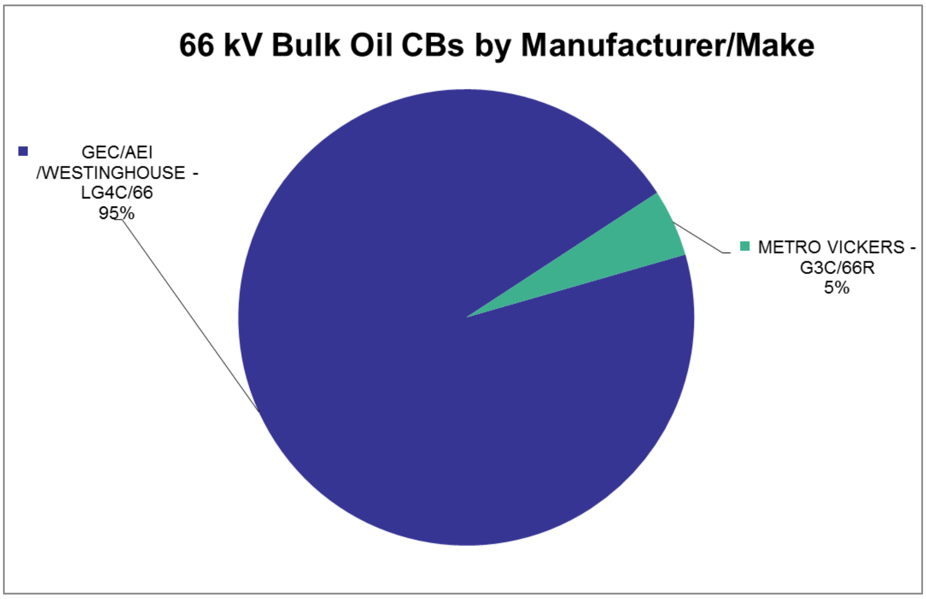

Figure 5 – 66kV Bulk Oil CBs by Manufacturer / Make

3.3 Asset Age Profile

The average service age of all distribution circuit breaker population is 28 years.
The average age of 6.6 kV and 11kV circuit breakers are 28.7 and 74.7 years. (Note: All kV circuit breakers (MPS and YPS) have been identified to be retired or replaced in 2019/20.)

Circuit Breakers with Vacuum and SF6 insulating medium are relatively new are introduced to replace older bulk oil and minimum oil circuit breakers. Table 1 & Table 2 below show the average age of the 22kV & 66kV circuit breaker population by technology type respectively.

22kV CB Type	Average Service Age (Years)	% 22kV CB Population
Bulk Oil	51.9	21.5%
Minimum Oil	39.9	13.6%
SF6	5.7	0.7%
Vacuum	15.2	64.3%

Table 1 - Average service age of 22kV distribution circuit breaker by type

66kV CB Type	Average Service Age (Years)	% 66kV CB Population
Bulk Oil	54.7	12.6%
Minimum Oil	44	33.7%
SF6	9.9	53.7%

Table 2 – Average service age of 66kV distribution circuit breaker by type

Figure 6 provides the population distribution of circuit breakers against the technology type. It is noted that bulk oil and minimum oil circuit breakers contribute to the aged circuit breaker population whereas the younger CB population is due to modern vacuum circuit breakers and SF6 insulated dead tank and live tank circuit breakers. There are also 7.1% of older vacuum type indoor circuit breakers in the 30-40 year age group, mainly due to indoor type vacuum circuit breakers in outdoor enclosures and older indoor switchboards installed in the 1980s.

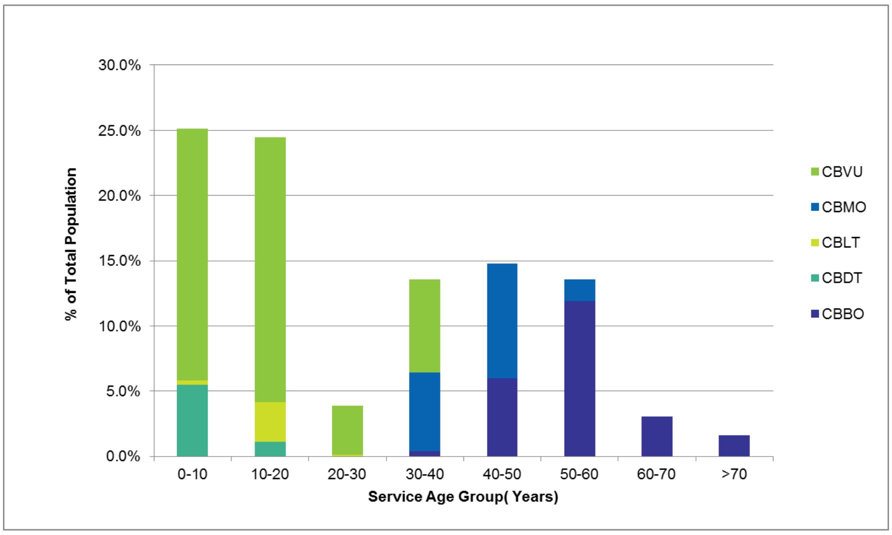

Figure 6 – CB Age by CB Technology Type

3.3.1 22kV Circuit Breakers

Figure 7 below show the age distribution of 22kV minimum oil and 22kV bulk oil circuit breakers in service.

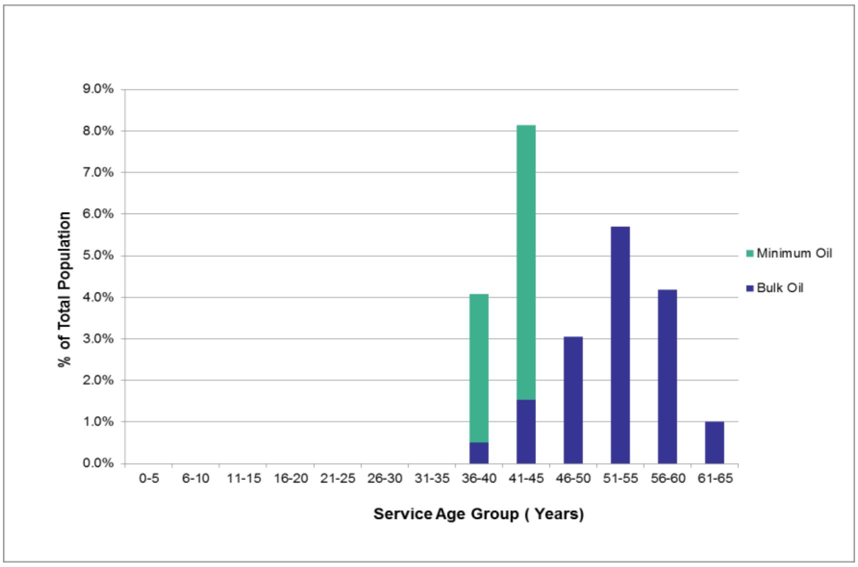

Figure 7- 22kV Bulk Oil and Minimum Oil CBs by Age

22kV minimum oil circuit breakers are mainly located in second generation indoor switchboards are reaching end of life, mainly [C.I.C] types (refer Figure 2). Managing these CBs are becoming difficult due to scarcity of original spares. Their service age fall within 35 - 45 year band. (Refer Figure 7)

78% of the 22kV bulk oil circuit breakers compromise of [C.I.C] and mostly over 40 years old and reaching end of life. Some spares sourced from retired CBs are available but the reliability of these CBs becoming poor.

3.3.2 66kV Circuit Breakers

Figure 8 below show the age distribution of 66 kV minimum oil and 66 kV bulk oil circuit breakers in service.

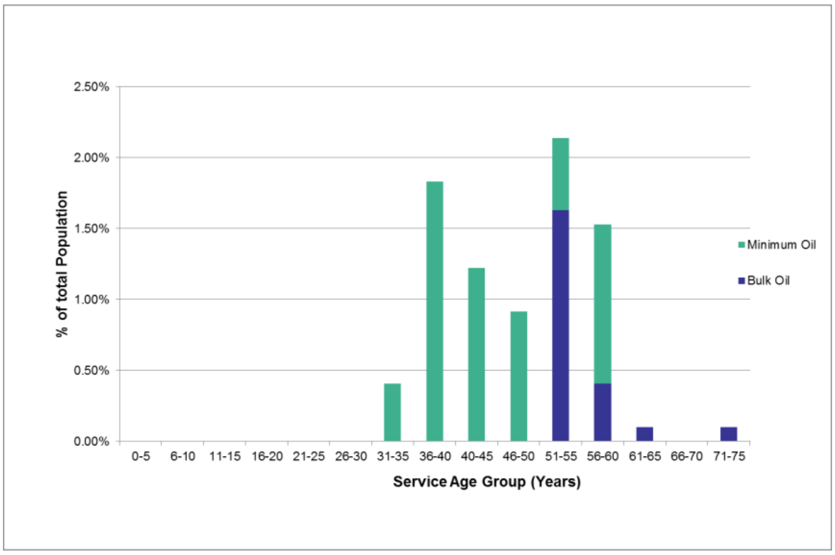

Figure 8- 66kV Bulk Oil and Minimum Oil CBs by Age

66kV minimum oil circuit breakers comprise of two types ASEA HLC, HLE, HKEYC and Sprecher & Schuh HPFC409k types. (Refer figure 4) They are more than 31 years old and oldest is 56 years. (Refer figure 8) [C.I.C] types are the oldest of the minimum oil circuit breaker fleet. Some spares sourced from retired CBs are available but the reliability of these CBs becoming poor.

66kV bulk oil circuit breaker population mainly comprise of [C.I.C] circuit breakers and has a smaller population compared to 66kV minimum oil circuit breakers. They are more than 50 years old. (Refer figure 8) Some spares sourced from retired CBs are available but the reliability of these CBs becoming poor.

3.4 Asset Condition

A circuit breaker CB Health Score has been assessed for each circuit breaker in the electricity distribution network.

CB Health Score of Zone substation circuit breakers are determined by considering the following factors.

1. Age
2. Normal Expected Life
3. Environment (Location factor)
4. Usage (duty factor)

5. Observations / Measurements
6. Reliability factors

Asset Indices Methodology used by Distribution Network Operators in UK and NIE[1] was used as a guidance to develop various factors to determine the Condition Score of Circuit Breakers in service.

Current Health Score is derived from calculation of initial asset score and applying condition based factors and reliability factors for each circuit breaker. For more information on condition scoring refer "Asset Health Report (AHR -20-54" & Excel Work Book "ZSS CB Condition Model")

The Table 3 provides a definition of the various condition scores and recommended action.

Condition Score	Condition Description	Summary of details of condition score	Remaining Service Potential (%)
C1	Very Good	These CBs are generally in good operating condition with no past history of significant 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 CBs which are in better than average condition. They may have some issues such as minor oil or SF6 leaks from seals, minor corrosion and some mechanism and drive system wear. They do not require intervention between scheduled maintenance nor do they show any trends of serious deterioration in condition or performance other than normal wear. Manufacturer support and spares are available.	70%
C3	Average	This category includes CBs which are with an average condition. They may have developed several issues due to in service related deterioration, such as interrupters wear, oil/SF6 leaks, corrosion, mechanism wear or re- adjustment required. These units typically require increased maintenance. Spares are being used to replace damaged components and manufacturer support for these breakers is becoming limited. The CB's are showing signs of deterioration in condition or performance.	45%
C4	Poor	This category includes CBs which are in worse than average condition. They may have developed an increasing number of issues such as interrupters wear out, worsening oil or SF6 leaks, significant contact and latching mechanism wear. They may also have a history of failures occurring such as bushing failures. Local manufacturer support and spares are typically not available and reverse engineering, salvaging parts from retired equipment or in situ repair are becoming the most practical solution. Specialist targeted maintenance is required to manage specific known defects.	25%
C5	Very Poor	This category includes CBs which are typically maintenance intensive and have history of, problematic interrupters, widespread oil and SF6 unrepairable leaks and repeated top ups, component breakages and typically worn out or unreliable operating mechanisms and significant failures. These CB's have substantial deterioration is approaching the end of economic life. The maintenance that can be performed to restore the condition is very limited due to lack of availability of spare parts and lack of experience and skill required to maintain the asset. They are no longer supported by the manufacturer. The maintenance of CBs in this category is typically no longer economical compared to asset replacement.	15%

Table 3- Condition Score definition and recommended action

Condition profile of distribution circuit breakers by voltage is shown in Figure 9.

[1] DNO Common Network Asset indices Methodology Framework of 30-01-2017 of UK & NIE

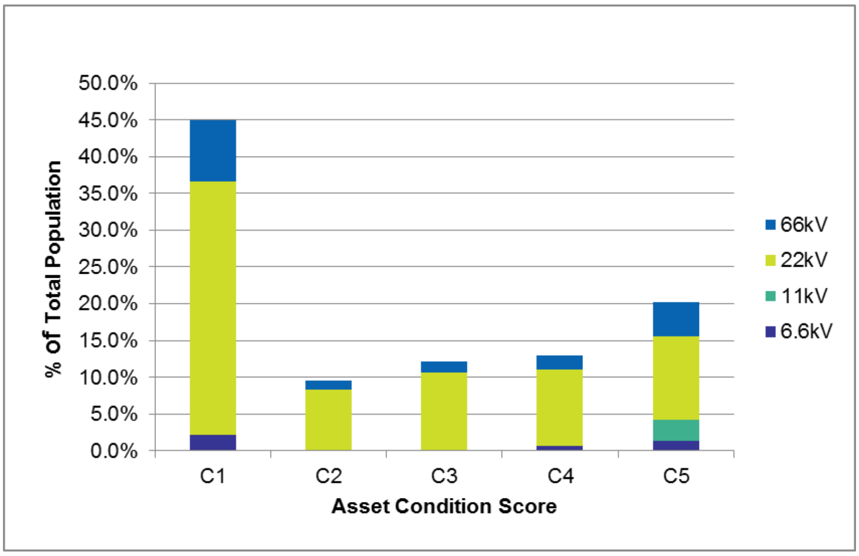

Figure 9 - Condition Profile of Circuit Breakers by Voltage Class

Asset Condition Score vs age profile is shown in Figure 10.

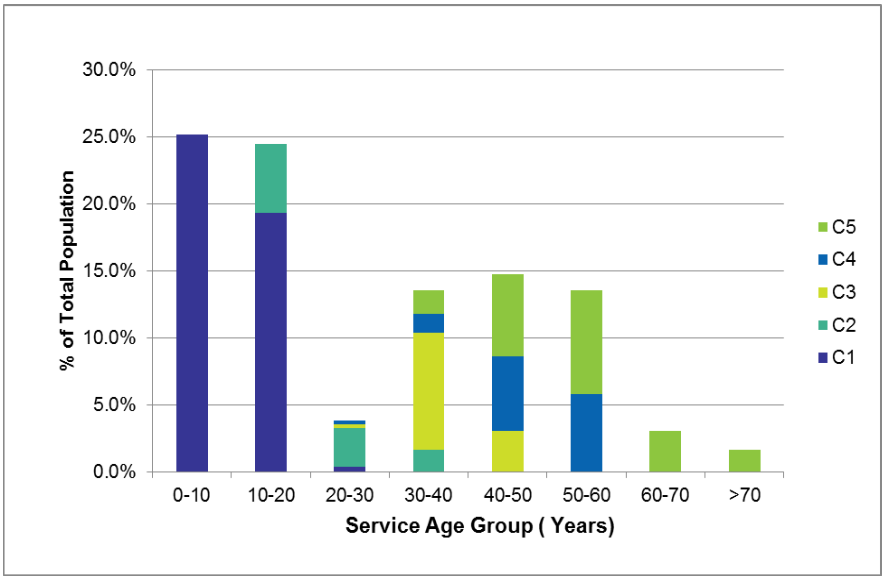

Figure 10 – CB Asset Condition vs Age

3.4.1 6.6kV and 11kV Circuit Breakers

Figure 11 provides the CB condition profile of 6.6kV and 11kV CB population.

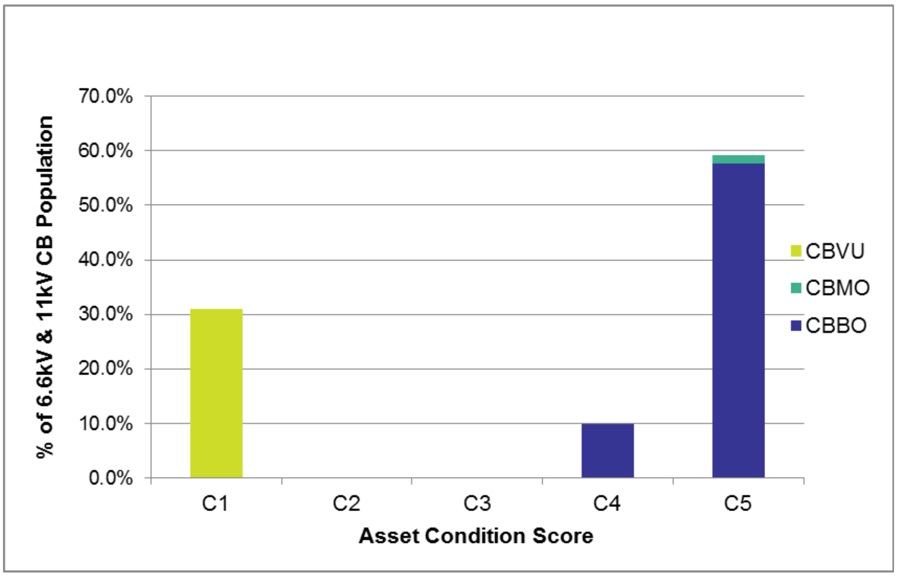

Figure 11 – CB Asset Condition Profile of 6.6kV & 11kV CB population

31.0% of 6.6kV & 11kV circuit breakers are in “Very Good” (C1) condition. Remaining 6.6kV & 11kV circuit breakers are either in “Poor” (C4) or “Very Poor” (C5) condition. These circuit breakers are located mainly in open cut substations, MPS and YPS 11kV yard. All 11kV circuit breakers (located at MPS) are in “Very Poor” (C5) condition. They are not economical to maintain and planned to be retired by year 2019. YPS 11kV currently is being rebuilt which is to be completed in 2019. Most open cut substations are expected to be retired in the next 10-15 years, hence no replacements are anticipated.

3.4.2 22kV & 66kV Circuit Breakers

Figure 12 and Figure 13 provides the 22kV and 66kV CB condition profile by CB technology type respectively.

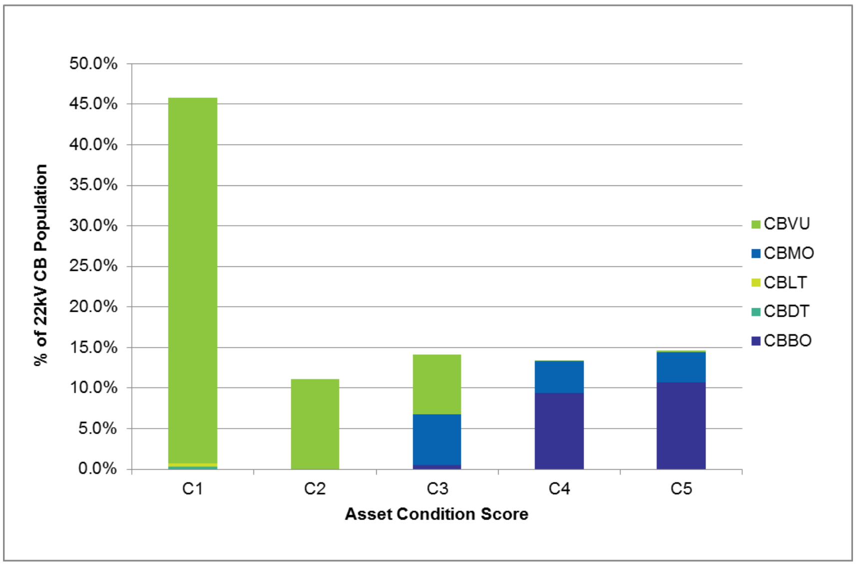

Figure 12 – 22kV CB Asset Condition Profile by CB type

45.8% of 22kV circuit breakers are in “Very good” (C1) condition. Approximately 28.1% of 22kV circuit breakers were assessed as “Poor” or “Very Poor” condition. (Refer figure 12)

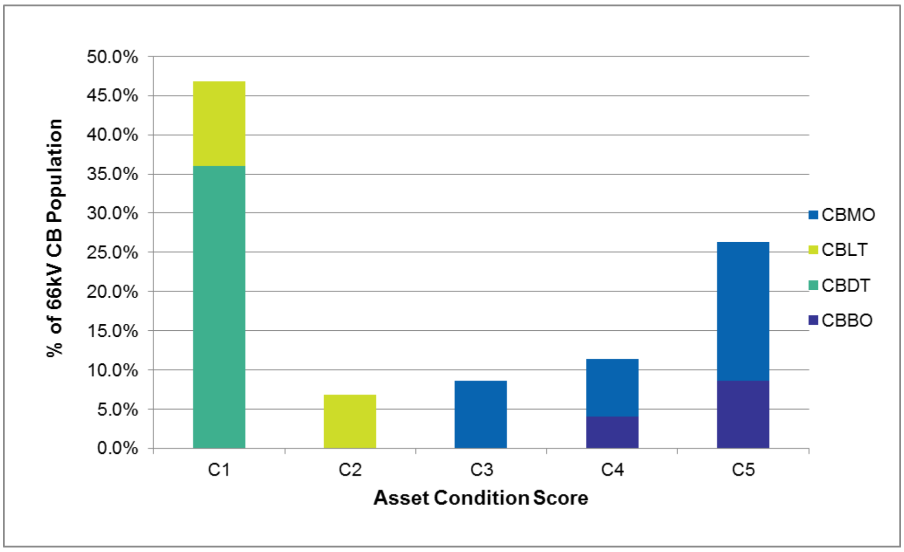

Figure 13 – 66kV CB Asset Condition Profile by CB type

46.9 % of 66kV circuit breakers are in “Very Good” (C1) condition. Approximately 37.7% of 66 kV circuit breakers were assessed as “Poor” (C4) or “Very Poor” (C5) condition. (Refer figure 13)

Some of the “Very Poor” condition 22kV and 66kV CB models are shown in Table 4 below.

C.I.C

3.5 Asset Criticality

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

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

Asset criticality is the severity of consequence in a major failure of a circuit breaker 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 CB bushings associated with older oil filled outdoor CBs, mainly bulk oil and minimum oil circuit breakers. Modern dead tank and live tank SF6 insulated circuit breakers have much lower risk due to the use of polymeric bushings and SF6 gas as the insulating medium against Oil. Most vacuum circuit breakers are installed in indoor switchboards and the safety risk is much lower than for equivalent outdoor circuit breakers.

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.

The Figure 14, 15, 16 shows the Relative asset criticality based on CB Technology, Service Voltage, and Asset Condition of CBs.

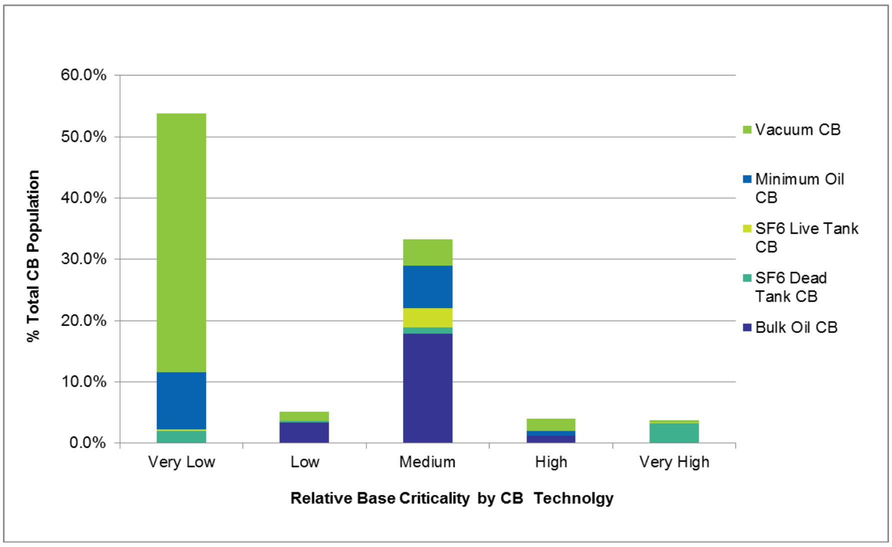

Figure 14 – Relative base criticality by CB Technology

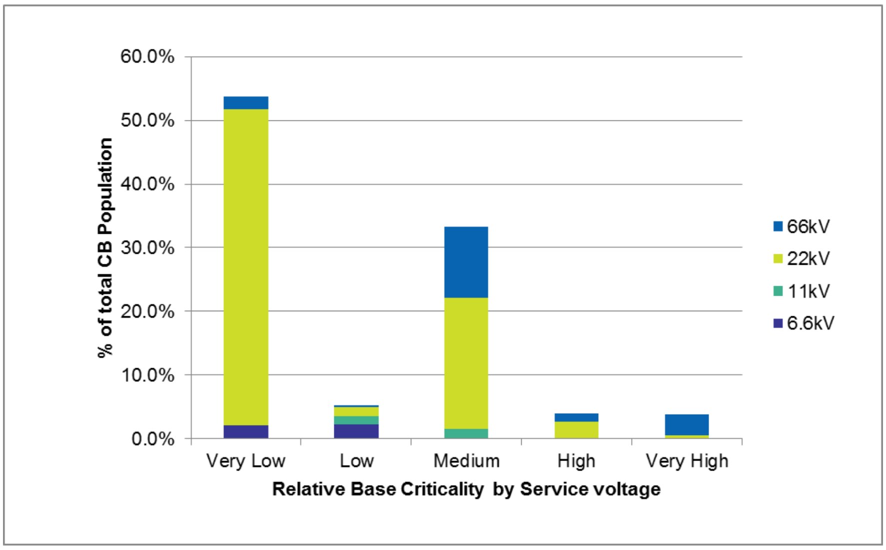

Figure 15 – Relative base criticality by Service Voltage

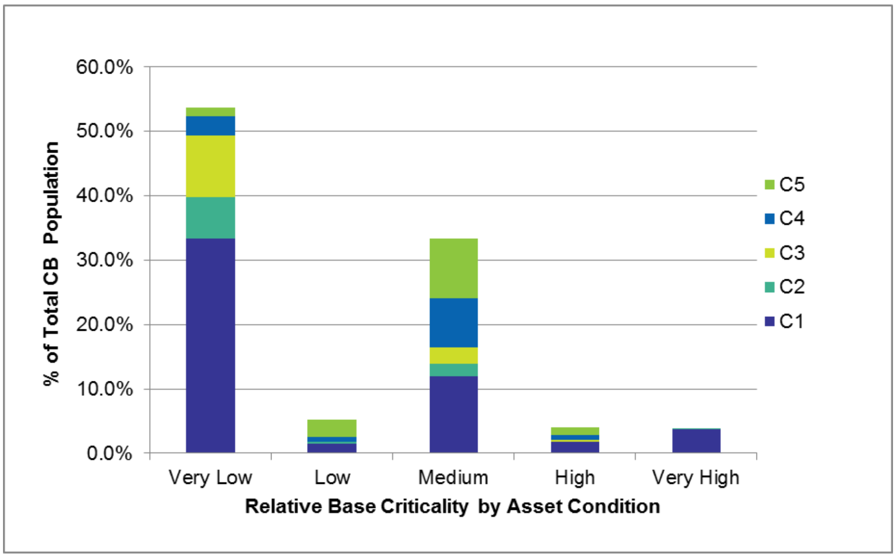

Figure 16 – Relative base criticality by Asset Condition

The applied interpretation of relative base criticality is shown in Table 5.

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

Table 5- Interpretation of Relative Base Criticality

Following observations are made on asset criticality:

- Approximately 26.8% of the medium to very high criticality on the relative data base are due to bulk oil and minimum oil CBs. (refer figure 14)
- Approximately 39.5% of the 22kV and 66kV CB population contribute to medium to very high criticality on the relative base. (Refer figure 15)
- Approximately 18.7% of the CB population have medium to very high relative criticality on the relative base are due to asset condition C4 and C5 circuit breakers. (refer figure 16)

3.6 Asset Performance

AusNet Services routinely analyses the root cause of unplanned work undertaken on circuit breakers and investigates all major failures, and tracks customer outages due to CB failures.

3.6.1 Corrective Maintenance

Records of unplanned maintenance work undertaken on circuit breaker population on the CB population are maintained in the Asset management system, SAP.

It is noted that the total number of corrective work orders per raised per CB type have come down over the years. (Refer figure 17) This is mainly due to replacement of older bulk oil and minimum oil circuit breakers with modern 66kV SF6 insulated circuit breakers and 22kV vacuum circuit breakers in indoor switchboards under station augmentation and asset replacement programs.

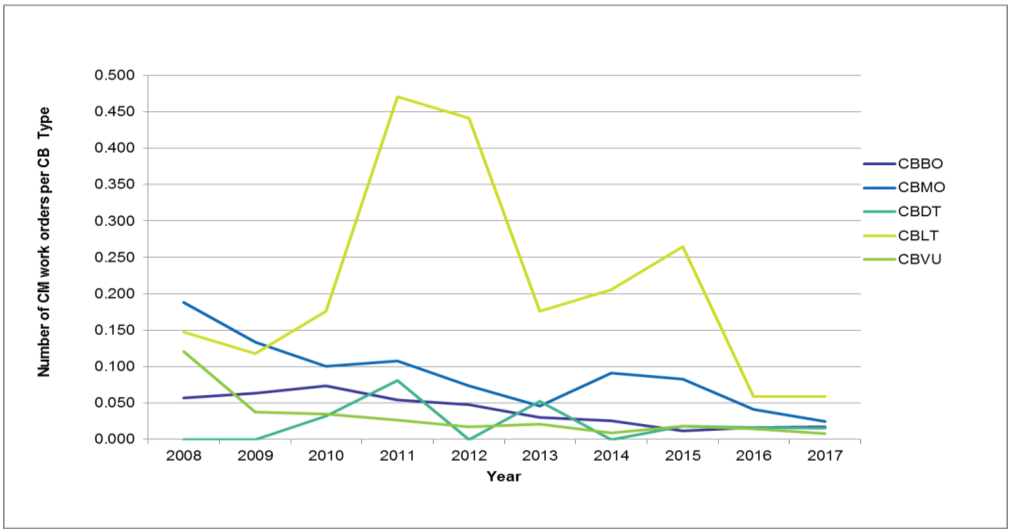

Figure 17 – Number of corrective work orders per CB fleet type 2008 – 2017

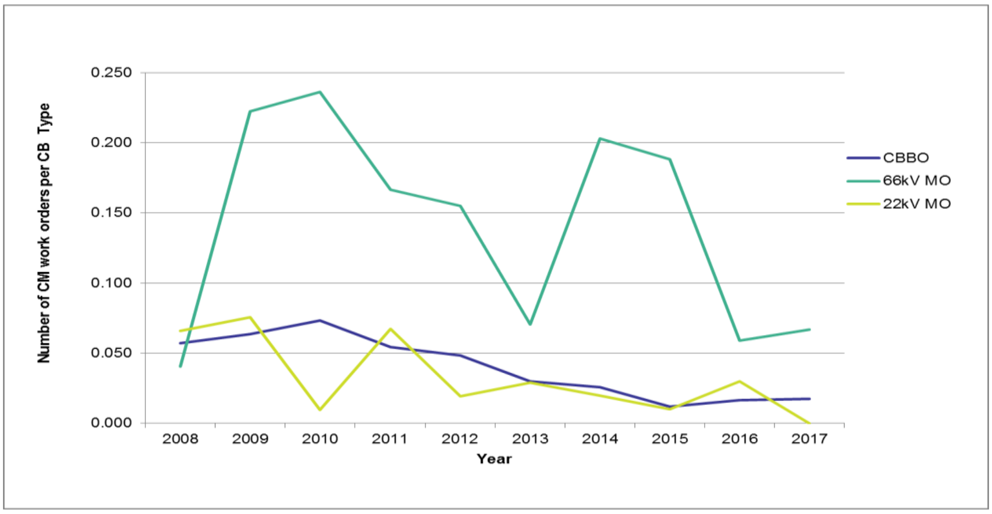

Figure 18 – Number of corrective work orders per bulk oil and minimum oil CB fleet type 2008 – 2017

Detail corrective work order analysis revealed following issues:

1. 22kV bulk oil CBs, 66kV minimum oil CBs and 22kV vacuum CBs contributed to the highest number of total corrective work orders.

2. 22kV bulk oil CBs had highest number of failures associated with mechanism, interrupter, CB auxiliaries and insulation systems, CB housing and number of unknown failures resulting in poor reliability of these CBs. But compared to 66kV minimum oil CBs and vacuum CBs it had a lower failure rate per CB fleet type against bulk oil type. (refer fig 17 & 18)

3. 66kV live tank CBs contributed to high number of corrective work orders mainly due to SF6 gas leakages due to poor seals. Corrective actions had reduced the number of failures on these CBs and their current performance has now improved. Due to their smaller population their failure rate per CB fleet was higher than all other types. (refer fig 17)

4. 22kV indoor minimum oil CBs had a lower failure rate compared to 66kV minimum oil CBs. Both 66kV and 22kV Minimum oil CBs are having higher number of ongoing issues due to oil leaks, CB interrupter, operating mechanism and auxiliary systems. Scarcity of spare parts due to technical

obsolescence has become the major challenge in maintaining the minimum oil CB fleet and while maintaining the reliability of their asset performance.

5. Although 22kV vacuum CBs contributed to highest number of work orders, the number of work orders per CB type is the lowest of all types due to their large population. Key issues were CB mechanisms, auxiliary system malfunctioning and vacuum interrupter failures in older CBs in indoor switchboards and step switches used in capacitor banks due to high operating duty.

Table 6 below provides the list of distribution bulk oil and minimum oil circuit breakers and their work order performance sorted in the descending order. (Worst performing CBs on top)

C.I.C

Older outdoor bulk oil and minimum oil circuit breakers have porcelain housings compared to modern polymer housed SF6 insulated circuit breakers. Oil leaks in the bushings as a result of seal failure cause gradual moisture ingress and result in insulating medium failure. This results in in catastrophic failure causing safety to personnel, collateral damage and customer impact due to long restoration times.

In an indoor switchboard a catastrophic failure of a minimum oil CB can result in significant collateral damage to adjacent compartments and internal bus bar damage. This could cause much longer restoration time and larger customer impact due to 22kV bus bar outages due to collateral damage.

Technical obsolescence, excessively worn out parts and non-availability of original spares parts are the key issues in maintaining the reliability of these older CBs apart from increased operating cost. Often parts are locally sourced or salvaged from retired CBs which are partly worn, deteriorated or weakened.

3.6.2 Major Asset Failures

Number of major defects and failures associated with distribution circuit breakers from 2008 -2017 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 circuit breakers which are technically obsolete. Refer section 4.3 for details of issues.

Figure 19 below shows the number of major failures /defects per year per 100 CBs against age group.

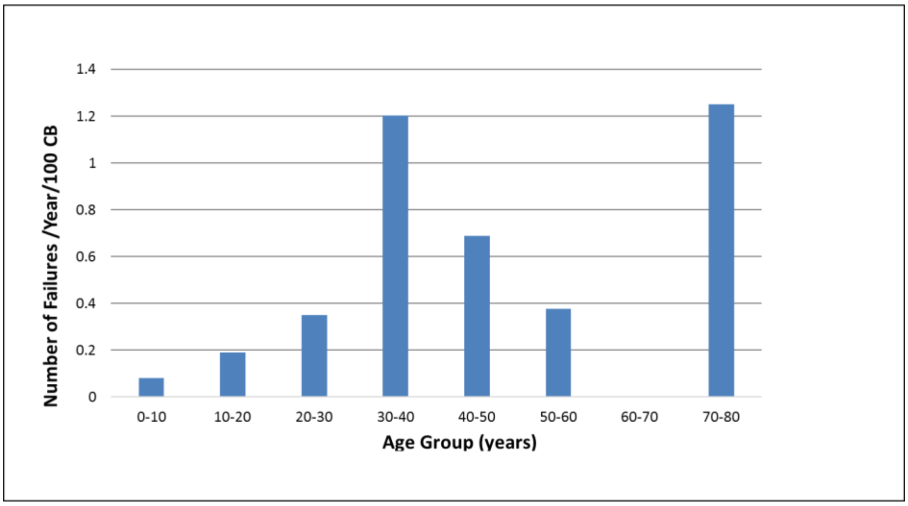

Figure 19 – Number of major failures /defects per year per 100 CBs (2017 population statistics)

3.6.3 Catastrophic Failures

There were two bulk oil circuit breaker major failures reported in 2014 and 2016 at YPS 11kV switchyard due to bushing failures, one incident resulted in a catastrophic porcelain bushing failure. Circuit breakers at this site are of [C.I.C] which are the oldest population of outdoor circuit breakers in Zone Substations.

Safety gram IMS 225933 was issued in 2016 restricting access to the YPS 11kV switchyard. Presently YPS 11kV switchyard is included in station access restriction document SOP35-01 after carrying out further bushing tests of the circuit breakers at this site. YPS 11kV switchyard is planned to be replaced by end 2019.

4 Other Issues

4.1 PCB in Bulk Oil and Minimum Oil Circuit Breakers

Older 22kV and 66kV bulk oil and minimum oil circuit breakers 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.
Circuit breakers which have been found to contain more than 2 mg/kg stipulated by the HSEQ guidelines (HSP 05-32) are treated as PCB contaminated and needs to be handled with care.

4.2 Asbestos in Older Oil Circuit Breakers

Asbestos containing material are found in older bulk oil circuit breakers such as [C.I.C] covers and panels used in control cubicles. 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 when CB's are older and could not normally obtain OEM spares parts beyond 30 years. Similarly, the specialist knowledge and ability of the manufacturer to overhaul / refurbish their circuit breakers will also diminish over time.
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 components and reverse engineering become the only means of supporting a fleet of circuit breakers. Ultimately, even reused components cannot economically extend asset lives further and at this point a circuit breaker will become obsolete.

In regard to indoor minimum oil circuit breakers, mainly [C.I.C] circuit breakers located in indoor switchboards are now technically obsolete and no manufacturer support is available and the availability of spares is very limited. Retrofitting these circuit breakers with indoor vacuum circuit breakers is an option but the retrofit solution needs customisation to match the existing switchboard technical requirements.

4.4 New Technology and Increased Customer Expectations

With the increased use of new technology by customers and their expectation of higher reliability of power supply require faster and reliable circuit breakers for fault clearing with the use of distribution feeder automation (DFA) and REFCL technology. Oil Circuit breakers built in 1960s are generally maintenance intensive and lower operating duty compared to modern vacuum and SF6 CBs. Also modern circuit breakers are provided with polymer housing /enclosures and fail safe compared to older circuit breakers provided with porcelain housing/ enclosure.

5 Risk and Option Analysis

Risk Assessment for distribution circuit breakers was performed using combined AWB / spreadsheet based quantitative risk method. AWB modelling was used to quantify the risk benefit of asset replacement against business as usual (BAU) on a five point condition scale (C1,C2,C3,C4 and C5) obtained for each circuit breaker from CB condition model (refer section 3.4).

NPV benefit during a 45 year asset life for each CB was calculated using the combined AWB / spreadsheet model using quantified effects of a major failure for different technology type of circuit breakers.

Following failure effects were taken into consideration for the risk model.

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

NPV benefit was derived for three replacement timing options, mainly replace now, replace in 5yrs and replace in 10 yrs. Circuit breakers that recommend replacement now and in 5 years (excluding the CBs already identified under current EDPR period) were identified for replacement in the EDPR 2022-26 period.

C.I.C

Model forecasts replacement of 135 circuit breakers between now and 2025 based on risk associated with individual circuit breaker compared to the cost of replacement over 45 year asset life.

The Table 8 below shows the proposed CB replacement strategy EDPR 2022-26 under the program.

CB Replacements	22kV	66kV	Total
Current projects 2018-2021 (REFCL, major rebuild and CB replacement programs)	26	19	45
Proposed Station Rebuilds - EDPR 2022-26	31	16	47
Proposed CB Replacement program - EDPR 2022-26	12*	20	32

Table 8 – Proposed Circuit Breaker replacement program 2018 -2026

*Note: It has been identified to focus on retrofitting of 12 minimum oil indoor circuit breaker types namely, [C.I.C] circuit breakers with vacuum circuit breakers in the next EDPR period 2022-26 due to technical obsolescence, asset collateral failure risk and operators safety risks. Replacement of four ACRs in poor condition at MDG and NLA will be managed during the current period. It is recommended to differ the replacement of other outdoor 22kV circuit breakers which has a marginal cost benefit ratio (ex: CYN and WO ZSS) to 2026-30 EDPR period to be considered under Station Rebuild.

Table 9 shows the key 22kV and 66kV CB types identified for replacement in the EDPR period 2022-26. These circuit breakers have reached end of life and are either minimum oil or bulk oil types which were found to be in “Very Poor” condition and had major technical issues as described in the preceding sections.

The outdoor CB types pose a significant safety risk to operators since housings of these CBs have porcelain housings and bushing failures could result in catastrophic failures. The electricity act requires AusNet services to design ,construct ,operate ,maintain and decommission its supply network to minimize hazards and risks ‘as far as practicable’ ,to the safety of any person arising from the supply network. Hence proactive replacement of this “Very Poor” condition high safety risk CBs would be practical approach to manage safety risks.

C.I.C

6 Asset Strategies

6.1 New Assets

- Specify outdoor SF_6 insulated dead tank/ polymer insulator circuit breakers for replacement in 66 kV installations.
- Specify indoor metal clad /arc fault rated vacuum interrupter circuit breakers in indoor modular switchboards for 22 kV installations.

6.2 Condition Monitoring

- Continue visual checks of circuit breakers as part of the regular zone substation inspections.
- Continue annual non-invasive condition monitoring scans including the use of radio frequency interference, ultrasonic, infra-red thermal and UV corona camera testing.
- Continue to establish the bulk oil CB's SRBP bushing condition through an electrical testing program

6.3 Maintenance

- Continue scheduled preventative maintenance as per specific Standard Maintenance Instructions for each circuit breaker type.

6.4 Spares

- Maintain strategic spares holding of circuit breakers as per spare holding policies
- Continue to salvage best parts and complete assemblies of obsolete CB to achieve per spare holdings

6.5 Refurbishment

- Use bushing replacements to mitigate shorter term risk until bulk oil CB replacement is possible, for "Very Poor" condition bushings found during the electrical testing condition monitoring program

6.6 Replacement

- Replace 47 circuit breakers as part of station rebuild projects at various zone substations by 2025.
- Replace 32 circuit breakers at various zone substations under CB replacement program by 2025.

7 Appendix 1 – Major Distribution Circuit Breaker Failures/ Defects 2008 - 2018

No		Voltage (kV)	CB Type	Year of Failure	Age at Failure	Station	Location Description	Location	Major failure / Defect
1	C.I.C	66	CBMO	2008	39	SLE	CB D	Line /Bus	mechanism failure -latch failure
2		22	CBBO	2008	50	MWTS	MWT 32	Feeder	Catastrophic bushing failure
3		22	CBBO	2008	40	ELM	ELM 32	Feeder	Trip latch and mechanism faulty
4		22	CBBO	2008	46	TGN	TGN 14	Feeder	Bushing contact failures
5		22	CBBO	2008	46	PHM	PHM 12	Feeder	Moving contact assembly of one phase broken
6		22	CBVU	2008	9	PHM	PHM 31	Feeder	Vacuum canister failure outdoor enclosure
7		22	CBMO	2008	30	LYS	??	Feeder	Mechanism issues
8		22	CBMO	2009	33	HPK	HPK 23	Feeder	seal failure -major oil leak from CB
9		22	CBMO	2009	33	HPK	TR 2	Transformer	seal failure -major oil leak from CB
10		66	CBMO	2009	27	BDL	CB B	Line /Bus	Mechanism failure
11		22	CBVU	2009	13	WGL	WGL 12	Feeder	Vacuum canister failure switchboard
12		66	CBLT	2010	11	BDSS	CB G	Line /Bus	major SF6 gas leak
13		66	CBMO	2010	43	SLE	CB A	Line /Bus	mechanism failure -latch failure
14		66	CBMO	2010	41	MYT	??	Line /Bus	Major oil leak needing seal replacements
15		66		2010	6	BWA	TR 2	Transformer	Ratchet wheel failure of mechanism -design fault subsequently corrected
16		22	CBBO	2010	48	WT	CAP BANK NO 2	Cap Bank	moving contact and pull rod broken
17		66	CBLT	2011	12	APM	CB A	Line /Bus	major SF6 gas leak
18		22	CBBO	2011	50	MWTS	MWT 32	Feeder	Major Bushing oil leak
19		22	CBVU	2012	6	WGI	WGI 21	Feeder	failure of operating mechanism
20		66	CBLT	2012	13	BDSS	CB C	Line /Bus	major SF6 gas leak
21		22	CBBO	2012	50	MOE	MOE 14	Feeder	mechanism failure
22		22	CBBO	2012	50	PHM	PHM 12	Feeder	Fixed contact assembly of one phase broken away

23		22	CBVU	2013	29	MOE	MOE 32	Feeder	CB Fail and station black on two occasions. Roller lubricated, trip coil replaced and returned to service
24		66	CBLT	2013	14	BDSS	CB E	Line /Bus	major SF6 gas leak
25		66	CBMO	2013	44	SLE	CB A	Line /Bus	mechanism failure -latch failure
26		66	CBLT	2014	15	BDSS	CB G ,D	Line /Bus	major SF6 gas leak
27		66	CBLT	2014	15	APM	CB A	Line /Bus	major SF6 gas leak
28		66	CBMO	2014	32	BDL	CB A	Line /Bus	Mechanism failure -worn
29		66	CBMO	2014	47	SLE	CB A	Line /Bus	mechanism failure -latch failure
30		11	CBBO	2014	78	YPS	S/S TR 2	Transformer	Catastrophic bushing failure
31		66	CBMO	2014	39	HPK	CB B	Line /Bus	Major oil leak needing seal replacements
32		66	CBMO	2014	37	HPK	CB A	Line /Bus	Major oil leak needing seal replacements
33		22	CBMO	2014	36	LYS	LYS 22	Feeder	Mechanism failure
34		66	CBLT	2015	16	BDSS	CB G	Line /Bus	SF6 gas leak
35	C.I.C	22	CBMO	2015	34	HPK	HPK 21	Feeder	seal failure -major oil leak from CB
36		22	CBVU	2015	19	WGL	WGL 14	Feeder	Mechanism failure
37		66	CBMO	2015	33	BDL	CB A	Line /Bus	Mechanism failure -worn
38		66	CBMO	2015	48	LGA	CB C	Line /Bus	Major oil leak needing seal replacements
39		22	CBMO	2016	35	BRA	BRA24	Feeder	mechanism failure -spring latch failure
40		22	CBMO	2016	38	WYK	WYK 23	Feeder	CB interrupter failure causing catastrophic failure
41		11	CBBO	2016	80	YPS	S/S TR 2	Transformer	Catastrophic bushing failure
42		22	CBVU	2016	17	CF	CF2	Feeder	spring winding failure of outdoor enclosure type unit
43		22	CBVU	2016	20	WGL	TR NO 1 /2	Transformer	Vacuum canister failure outdoor enclosure
44		66	CBMO	2017	35	SLE	CB D	Line /Bus	Major oil leak needing seal replacements
45		22	CBBO	2017	56	MWT	MWT 12	Feeder	contact operating rod broken
46		22	CBBO	2017	49	ELM	ELM 13	Cap Bank	Major Bushing oil leak
47		22	CBVU	2017	36	FTR	1-2 BUS TIE	Feeder	Mechanism latch failure
48		22	CBVU	2018	11	WN	1-2 BUS TIE	Feeder	Gas leak, Moisture ingress, internal corrosion and VCB failure
49		66	CBMO	2017	35	SLE	CB C	Line /Bus	Mechanism latch failure. BLG104 Mechanism.