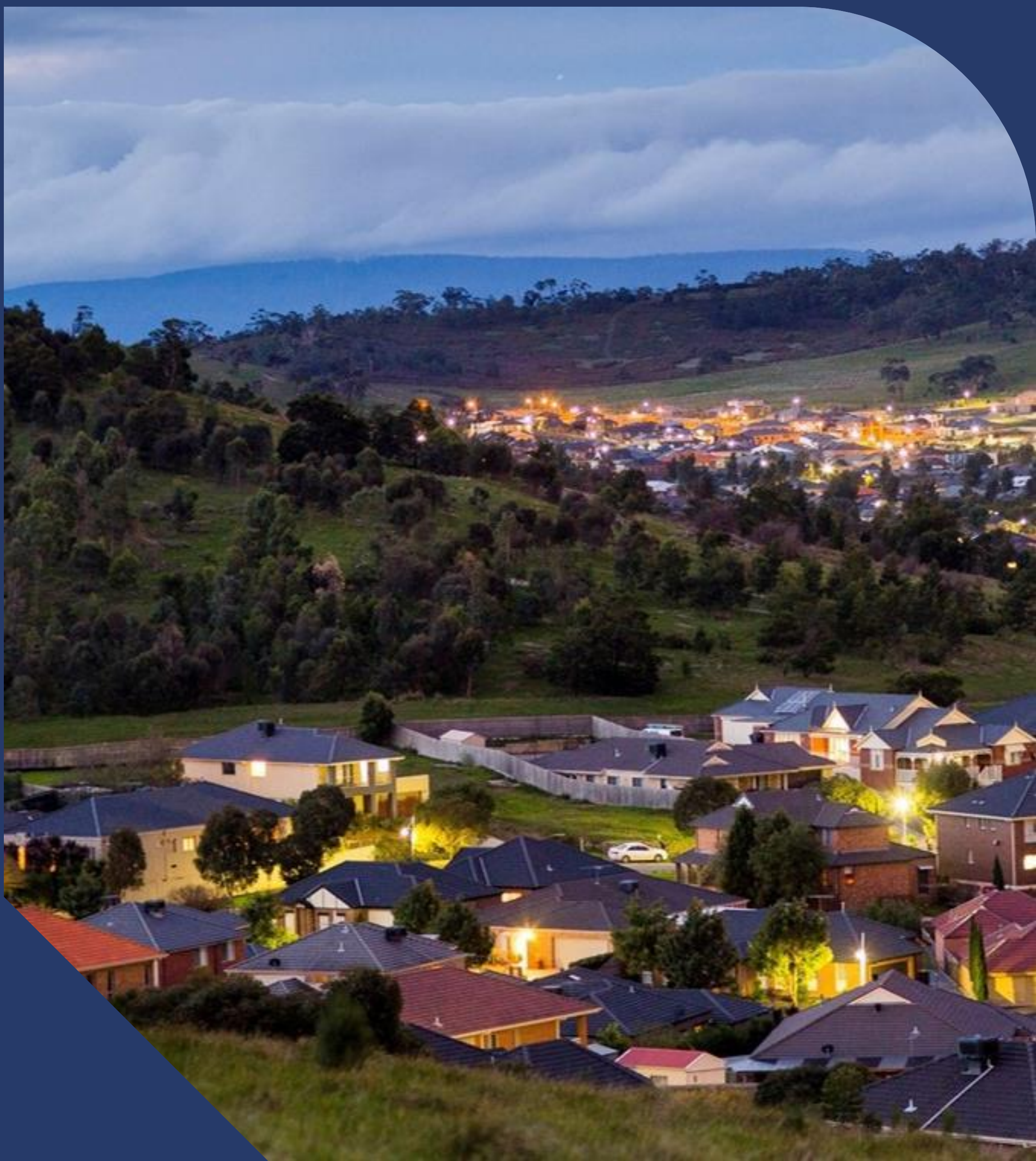
AusNet

Circuit Breakers

Asset Management Strategy



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Abbreviations and Definitions

TERM	DEFINITION
AMS	Asset Management Strategy
CB	Circuit Breaker
CBBO	Bulk Oil Circuit Breaker
CBDT	Dead Tank Circuit Breaker
CBLT	Live Tank Circuit Breaker
CBMO	Minimum Oil Circuit Breaker
CBVU	Vacuum CB
COF	Consequence of Failure
GIS	Gas Insulated Switchgear
POF	Probability of Failure
RIN	The Regulatory Information Notice
SAP	Brand name for enterprise-oriented database software
SVC	Static Voltage Compensator
ZK	Work order Notifications associated with failures (unplanned power interruptions)
ZA	Work order Notifications associated with corrective actions from planned inspections

1. Executive Summary

This document outlines AusNet's asset management strategy for high voltage circuit breakers (CBs) within the regulated electricity transmission network. It details the approach to inspection, maintenance, monitoring, and targeted replacement of CBs, stiving for ongoing compliance with regulatory standards and responsible, economically justified lifecycle management. The strategy addresses the challenges presented by a diverse and ageing fleet of over 1,013 CBs, spanning a wide range of technologies, voltages (4.5kV to 500kV), and manufacturers.

A risk-based assessment has been undertaken, focusing on the consequences of failure including community impact, safety, environmental, and market considerations. Particular attention is given to porcelain housed and oil-filled CBs, which pose heightened safety and environmental risks due to explosive and fire hazards. The assessment supports a targeted replacement program for 2027 and 2032, with priority given to obsolete models and those with known performance or reliability issues.

The strategy emphasises proactive management through scheduled preventative maintenance, non-invasive condition monitoring, and periodic electrical testing. Key risks include technical obsolescence, limited OEM support, and increasing failure trends among older CBs, especially bulk oil and minimum oil types. The plan aims to satisfy stakeholder expectations for safety, reliability, cost effectiveness, and environmental responsibility are consistently met through ongoing maintenance, monitoring innovations, and the systematic replacement of at-risk circuit breakers.

1.1. Asset Strategy Summary

AusNet's asset strategy for high voltage circuit breakers focuses on proactively managing risk, ensuring safety, and maintaining reliability through a targeted program of replacement, refurbishment, and maintenance activities. The approach prioritises the replacement of high-risk and obsolete circuit breakers, including:

- 66kV [C.I.C] and 22kV [C.I.C] Bulk oil circuit breakers
- 220kV [C.I.C] Minimum Oil circuit breakers
- High operation duty Live tank SF6 circuit breakers reaching wear out limits, e.g. [C.I.C], [C.I.C] and [C.I.C]
- 66kV [C.I.C] Minimum Oil circuit breakers (as part of a major program work)
- 330kV [C.I.C] AND [C.I.C] Minimum Oil circuit breakers CBs (part of major program work)
- 500kV [C.I.C] 3AT5 Live tank SF6 circuit breakers (as part of a major program work)

The strategy incorporates ongoing use of non-invasive condition monitoring techniques, such as thermal imaging and ultrasonic testing, alongside offline electrical testing of bushings to identify emerging issues before failure occurs. Scheduled preventative maintenance will continue in line with substation maintenance instructions (SMIs), which are tailored by circuit breaker type and meet or exceed manufacturer recommendations.

Where original equipment manufacturer (OEM) support remains available, high-operation live tank SF6 circuit breakers will be refurbished. Prioritised with particular focus on those serving capacitor banks, reactors, generators, or exhibiting persistent mechanism faults. Targeted repairs, such as addressing SF6 leaks, will be performed when viable.

To further manage lifecycle risks, the strategy includes regular review of strategic spare parts holdings, with consideration given to dynamic inventory levels as OEM support nears its end. Salvaging usable components from decommissioned equipment will continue to support ongoing maintenance needs.

This comprehensive, risk-based asset strategy aim to satisfy stakeholder expectations for safety, reliability, cost effectiveness, and environmental responsibility.

2. Introduction

2.1. Purpose

The purpose of this document is to outline the inspection, maintenance, replacement and monitoring activities identified for economic life cycle management of circuit breakers in AusNet Victorian regulated electricity transmission network. This document is intended to be used to inform asset management decisions and communicate the basis for maintenance, replacement and monitoring 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 regulated transmission asset base outdoor and indoor type circuit breakers (CBs)operating at 500kV, 330kV, 275kV, 220kV, 66kV, 22kV, 6.6kV[1] and 4.5kV located in terminal stations.

The following related assets are excluded from this report:

- Circuit Breakers installed in GIS/Metalclad Switchgear (covered by AMS 10-62).
- Unregulated Circuit Breakers

2.3. Asset Management Objectives

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

Trusted to bring the energy today and build a cleaner tomorrow							
Strategic Pillars						Ambition	
Safely deliver our customer's energy needs today				Create the energy network of tomorrow	Enable the transition to a net zero future	Be a leader in asset management practice	
Asset Management Objectives						Enabling AMOs	
Safety: Minimise risk to our people, contractors, customers and communities AFAP across our networks	**Reliability:** Meet the reliability expectations of our customers and communities, and meet our reliability targets	**Resilience:** Improve the resilience of our network to adapt to a changing climate and energy system environment	**Compliance:** Comply with all legislation, regulations, relevant standards and industry codes	**Planning and decision-making:** Deliver valued planning and network outcomes through optimising asset lifecycle management	**Sustainability:** Build stakeholder trust and deliver social value. Reduce our environmental impact. Operate efficiently to sustain financial value creation.	**Competency and capability:** Develop asset management capability and competency in the organisation	**Continuous improvement:** Continually improve asset management maturity for effective delivery of services

[1] All six 6.6 kV circuit breakers at TSTS are out of service and part of the synchronous condenser supply circuit. Both will be decommissioned under the terminal station rebuild project, due for completion in 2026. Therefore, all 6.6 kV CBs are excluded from this AMS document.

3. Asset Description

3.1. 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 to prevent injury and protect property.

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

3.2. Population

AusNet has a total of 1013 circuit breakers (CB) installed in the electricity transmission network as of 22 Sep 2025.

3.2.1. Population by Object Type

A summary of the transmission circuit breaker population by voltage and objective type are shown in figure 1 and 2.

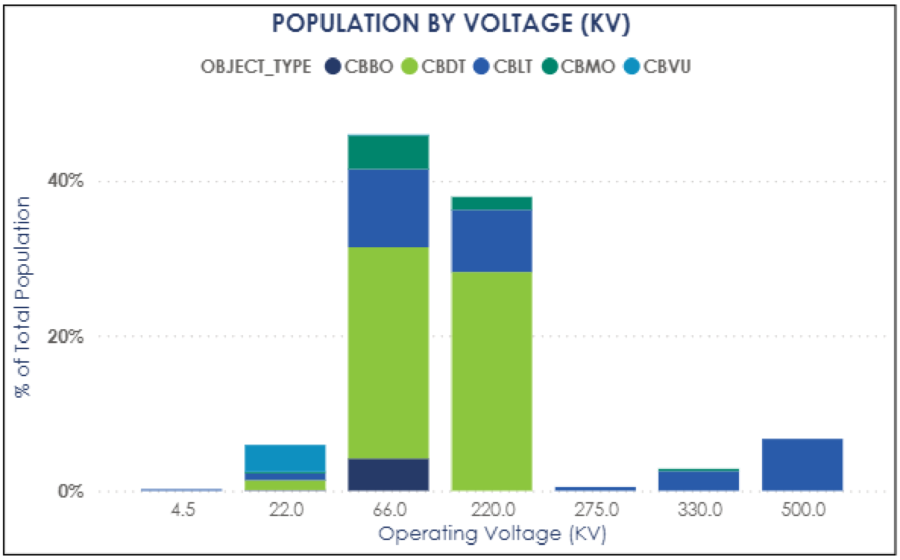

Figure 1: Circuit Breaker population by Voltage

There are only two 4.5kV CBs on the AusNet network. These are special application CBs used for SVC filtering.

The full quantity of six 6.6kV CBs are currently used for auxiliary supplies at Templestowe Transmission Station (TSTS). These are [C.I.C] LMT bulk oil CBs, but these are already planned for replacement, so have been excluded from further judgement in this AMS.

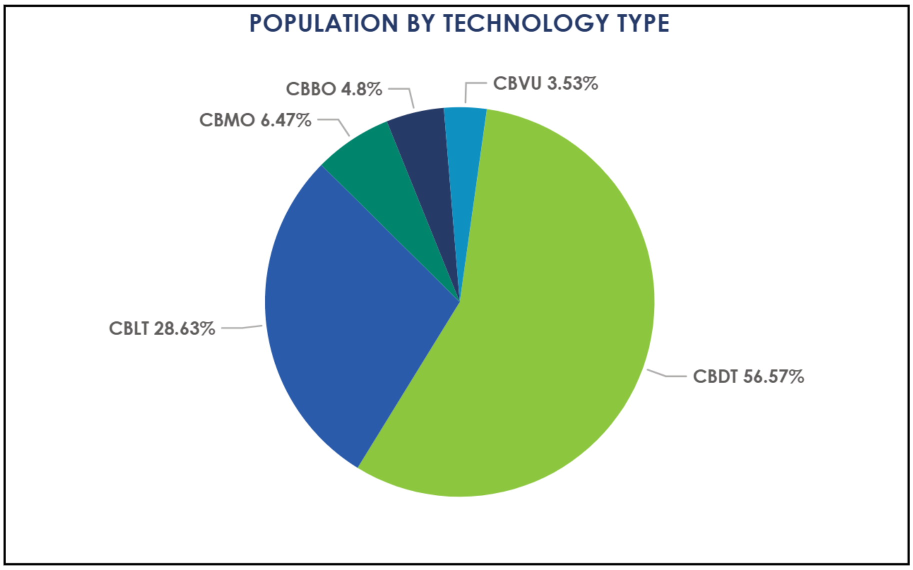

Figure 2: Circuit Breaker population by Technology Type

Most circuit breakers are SF6 insulated, dead tank (CBDT) type, and live tank (CBLT) type. Approximately 11% of population are oil insulated, either outdoor bulk oil (CBBO) type and minimum oil (CBMO) type. The small remainder are indoor switchboard vacuum type (CBVU).

Approximately 46% of the circuit breakers operate on 66kV system and comprise of 37.32% off SF6 insulated (CBDT & CBLT), 4.34% off minimum oil (CBMO) and 4.15% of bulk oil circuit breakers (CBBO).

3.2.2. Population by Manufacturer

Figures 3 ,4 and 5 below provide the population distribution of 220kV and above Live Tank, all Bulk Oil and Minimum Oil circuit breakers by top 10 Manufacturer/Model.

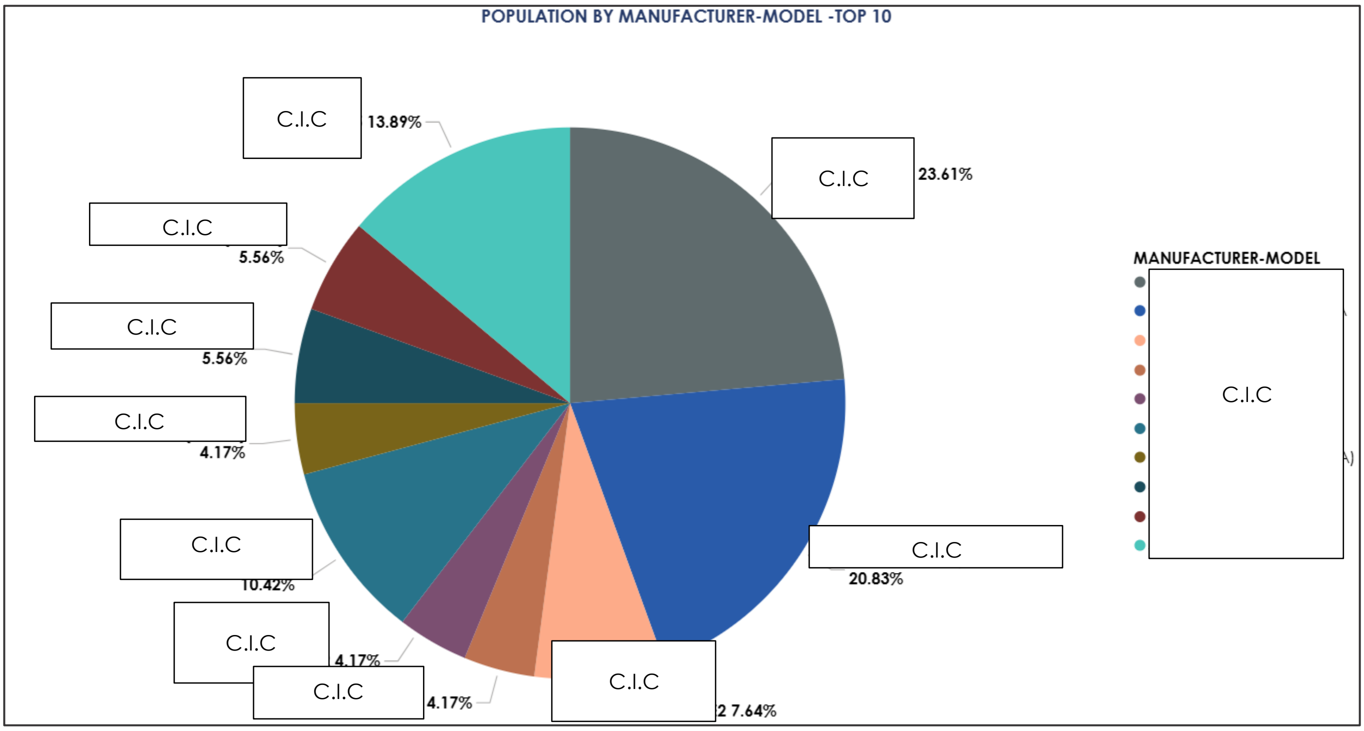

Figure 3: 220kV and above Live Tank Circuit Breakers by Manufacturer / Make

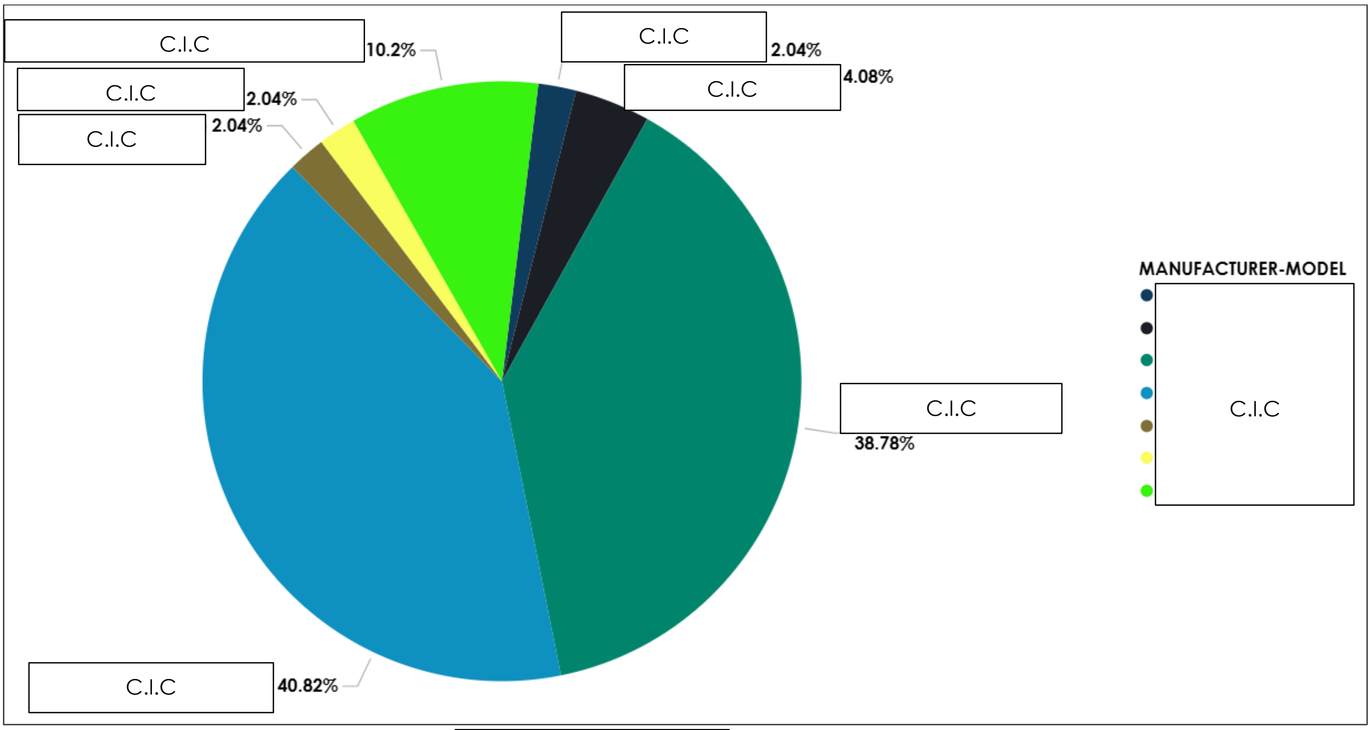

Figure 4: C.I.C by Manufacturer / Make

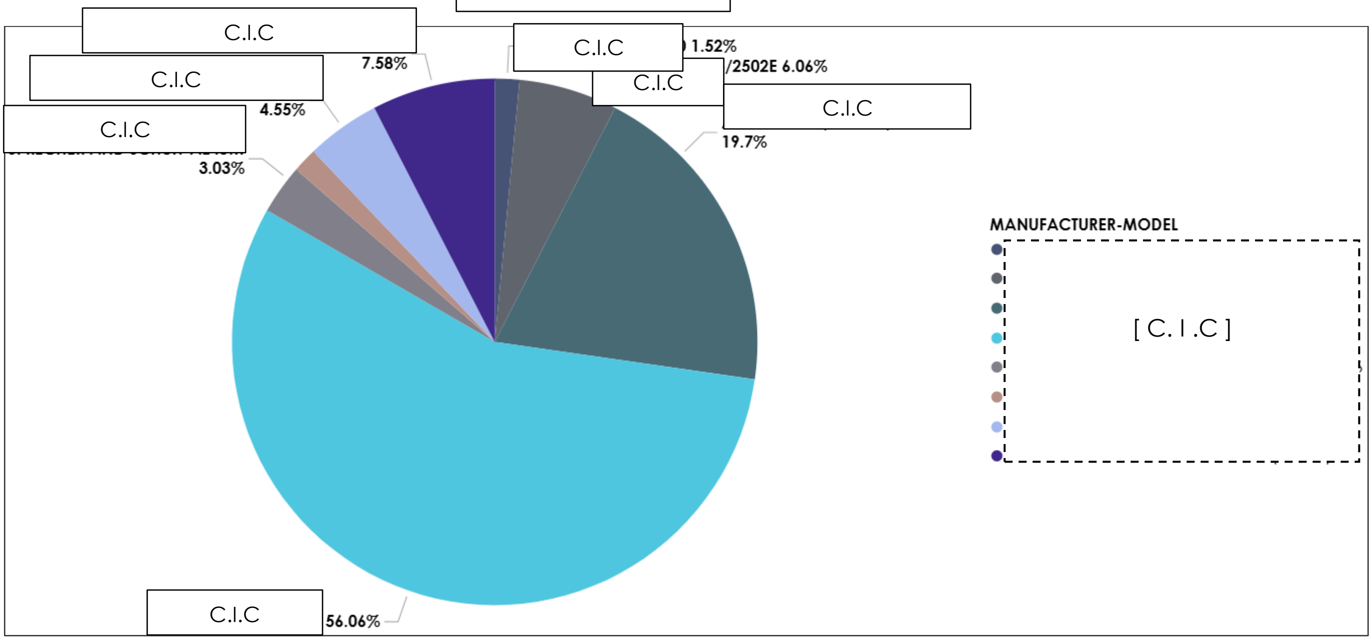

Figure 5: Minimum Oil Circuit Breakers by Manufacturer / Make

The following key observations have been made:

There are a wide range of circuit breaker makes, models, voltage, and current ratings currently in use across the transmission network, operating from 4.5kV to 500kV. Live tank circuit breakers show the greatest variation, with the main types being Bulk Oil (4), Dead Tank (SF6) (20), Live Tank (SF6) (32), Minimum Oil (8), and Vacuum (5). This diversity introduces complexity for asset management strategies concerning maintenance, spare parts, and lifecycle planning.

For Live Tank Circuit Breakers (220kV and above), the primary models are (23%), [C. I . C] (21%), [C. I . C] (14%),[C. I . C] (11%), and [C. I . C] (8%). These models account for 77% of the[C. I . C] breaker population. [C. I . C] has three models that represent 52% of this segment, indicating its significant presence within this equipment category.

Within Bulk Oil Circuit Breakers, most are installed at 66kV and are predominantly of the [C. I . C] (86%). There is also a single remaining 22kV [C. I . C] CBBO, which has limited statistical significance but is still considered in the analysis. [C. I . C] LMT CBBO circuit breakers are scheduled for replacement and are not included in the detailed review presented here.

Regarding Minimum Oil Circuit Breakers, about 83% of units are [C. I . C] (56%) or [C. I . C] (26%).

AusNet has been systematically replacing CBBO fleets for over 20 years and CBMO over the last decade. These older technologies pose challenges related to aging infrastructure, increased maintenance requirements, environmental factors, and lack of OEM support. As similar circuit breaker types tend to experience comparable degradation patterns, early replacement was undertaken to reduce the risk of simultaneous failures, support resource allocation, and maintain network reliability. This approach is consistent with established asset management practices and assists in transitioning to modern circuit breaker technologies such as CBDT and CBLT.

3.3. Age

The mean service age of the transmission circuit breaker population is about [C. I . C] . Table 1 below shows the average age, youngest and oldest circuit breaker age by object type.

OBJECT_TYPE	Average Age (Yrs)	Youngest Age (Yrs)	Oldest Age (Yrs)
CBVU	17	1	20
CBMO	43	26	59
CBLT	22	0	45
CBDT	12	0	24
CBBO	57	45	60

Table 1: Service Age Profile of Transmission circuit breaker by Object type

It is noted that bulk oil, minimum oil and first generation SF6 CBLT contribute to the aged circuit breaker population whereas the younger CB population is due to SF6 insulated dead tank, modern live tank and vacuum circuit breakers.

The earliest 220kV CBDT installed are just over 20 years old and approaching mid-life. Gas seals slowly deteriorate with age, creating potential for trends towards SF6 leakage and while this is currently not the case, these CB's will be monitored for potential developments. Any early examples of gas leaks will be refurbished by exception.

Figure 6 and Figure 7 provides the population distribution of transmission circuit breakers against the object type and operating voltage.

It is noted that approximately 4.6% of the total CB population is more than 50 years of age and all of them are bulk oil circuit breakers at 66kV and one at 22kV. This also shown below in Figure 6.

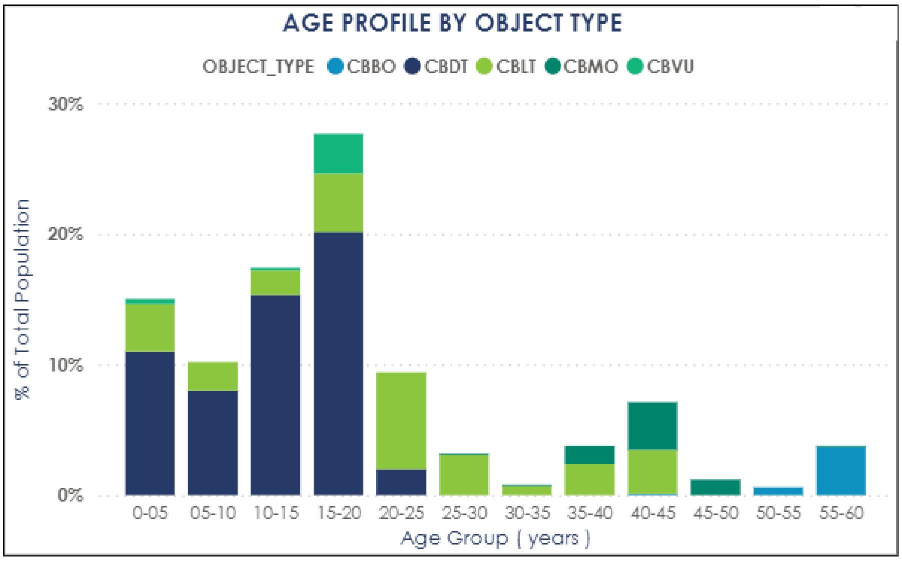

Figure 6: Service Age Profile by CB Object Type

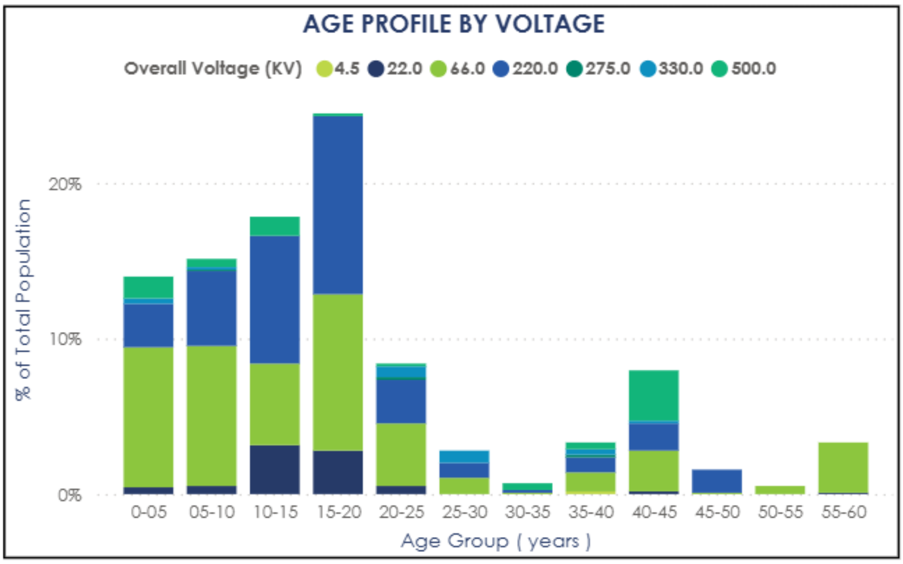

Figure 7: Service Age Profile by CB by Operating Voltage

4. Asset Performance

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

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

Performance data helps identify trends and patterns in asset behaviour, which are crucial for making strategic decisions regarding maintenance, upgrades, and replacements. Understanding how assets perform over time allows for proactive management, reducing the risk of unexpected failures. The assessment employed by AusNet involves analysing failure trends and any significant impacts resulting from failure, which provides valuable insights into the health and reliability of the assets.

4.1. Defect Analysis

4.1.1. Notification data

Records of unplanned maintenance work undertaken on AusNet circuit breakers are stored in SAP, the Asset management system and visualised through dashboards. Below are several visualisations of the notification data.

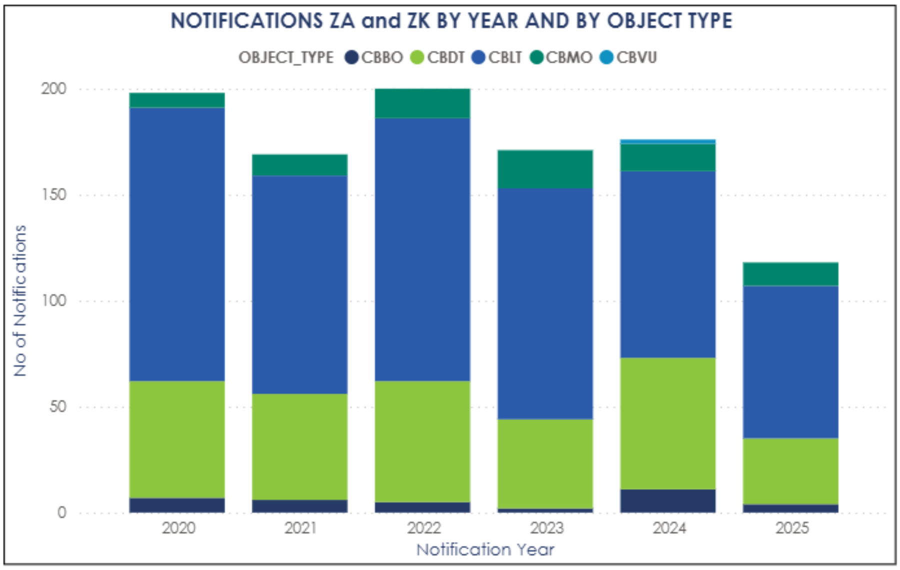

Figure 8: Number of ZA and ZK Notifications per CB object type 2020 – mid 2025

The chart above shows ZA (defect triggered corrective maintenance) and ZK (failure triggered corrective maintenance) notifications from 2020 to mid-2025. CBLT and CBDT consistently make up the majority of notifications, primarily due to leaks requiring SF6 top-up. There is a marked increase in notifications between 2021 and 2022, which may correspond with changes in maintenance activities during the COVID-19 restrictions. From 2023, the count of notifications has dropped back to normal level due to the removal of COVID-19 restriction. These observed patterns can assist in prioritising maintenance planning and resource allocation for different asset types.

Overall Trend suggests there is a general increase in the total number of notifications from 2020 to mid-year 2025 suggesting either improved reporting, increased asset activity, or a rise in issues being flagged.

CBLT (navy blue) is the most consistently significant contributor across all years, although it is acknowledged that size of an asset type's population will sway the numbers when considering number of notifications alone. Notifications versus percentage populations of object type are therefore afforded more detailed analysis in this section.

The above chart is helpful in identifying year on year variance, illustrating emerging or declining categories, such as CBBO, CBMO and CBVU. CBBO had a step change in 2023, potentially due assessment requirements across the fleet, following a single equipment failure that year. This object type also has been undergoing a program of planned replacements, which peaked in 2023. CBMO maintains a modest but steady presence, suggesting a stable notification pattern, although this pattern remains relatively high in terms of percentage of population.

The chart below showing notifications per year and voltage tells us notification numbers have decreased steadily over the five year period, with the most significant rise occurring between 2021 and 2022. The 220kV (light green) and 66kV (dark blue) voltage levels consistently account for the majority of notifications, while higher voltages such as 330kV and 500kV contribute less overall.

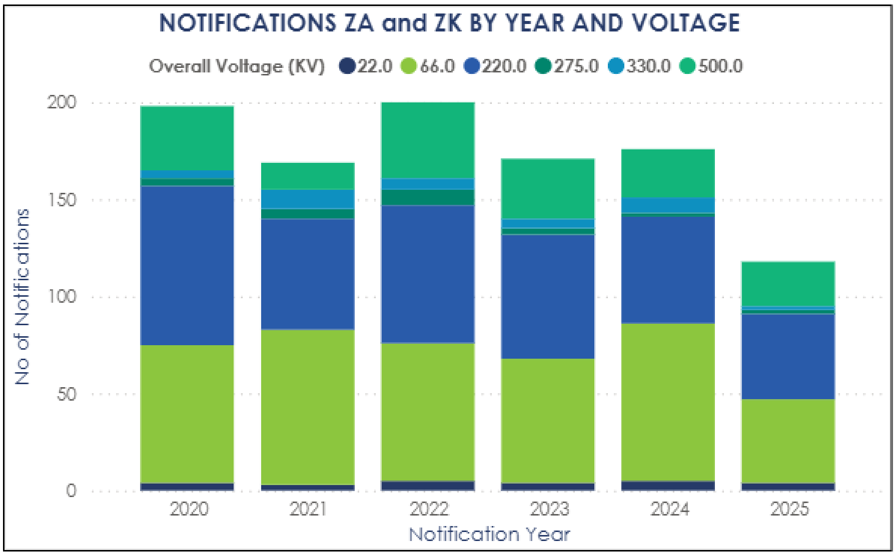

Figure 9: Number of ZA and ZK Notifications Vs Operating voltage 2020-mid 2025

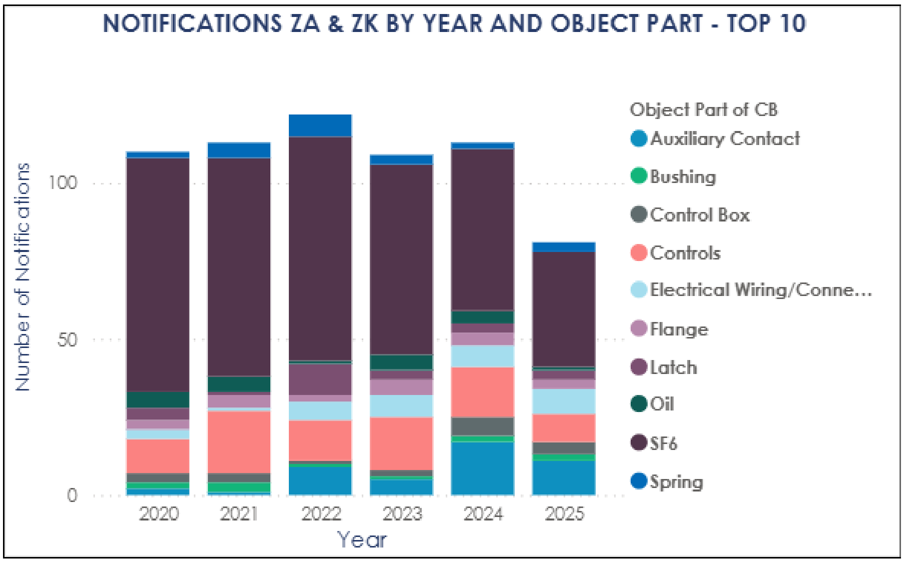

Figure 10: Notifications ZA and ZK by Year and Object part – top 10

Figure 10, titled "notifications ZA and ZK by year and object part – top 10," offers another lens for examining asset condition by focusing on specific circuit breaker components and their associated failure notifications from 2020 to mid-year 2025. Rather than grouping by object type or voltage, it highlights which parts, such as bushings, control boxes, and electrical connections are most frequently flagged. This view helps pinpoint recurring issues at the component level, supporting more targeted maintenance and reliability strategies.

Based on this information, an active CB bushing replacement program has been implemented, utilising salvaged bushings to address deteriorated CBBO bushings that pose a risk of catastrophic failure. However, the supply of salvaged bushings is nearly exhausted, and no alternative replacements are currently available. This indicates that refurbishment is no longer a viable strategy, and full replacement has become the only feasible option moving forward.

4.1.2. Detailed Analysis of Notification

Table 2 below provides high level insight into the performance and reliability of transmission circuit breaker types based on notification metrics. Among the categories, 1st generation CBLT show the highest population notification rate at 91%, and with an average of 5.86 notifications per CB from 2020 to mid-2025, indicating potential aging or reliability concerns. In contrast, the latest generation of CBLT have a lower notification rate of 52% and a significantly lower average of 1.96 notifications per CB during the same period, suggesting improved performance in newer models. Dead Tank breakers, despite having the largest population of 575 units, show a lower population notification rate of 33% and the lowest average notifications per CB among major types (0.71), implying better overall reliability. CBMO and CBBO types also exhibit relatively high population notification rates (62% and 70%, respectively).

EQ_OBJECT_TYPE	Number of Notifications	Number of CB with Notifications	Total CB Population	Percentage of CB Notifications Rate	Average Notification per CB
CBLT					
Latest Generation SF6 CB	444	118	226	52%	1.96
1st Generation SF6 CB	381	59	65	91%	5.86
CBDT	**411**	**191**	**575**	**33%**	**0.71**
CBMO	**125**	**41**	**66**	**62%**	**1.89**
CBBO	**56**	**30**	**43**	**70%**	**1.30**
CBVU	**2**	**2**	**36**	**6%**	**0.06**

Table 2: Number of ZA and ZK Notifications per CB (Overall) Object Type 2020-mid 2025

Objective Type	Make	Model	Number of Notifications	Number of CB with Notifications	Total CB Population	Percentage of CB with Notifications	Average Notification per CB
CBLT (1st generation)	[C.I.C]	3AT5	106	20	20	100%	5.3
CBMO	[C.I.C]	HLR84	50	23	37	62%	1.4
	[C.I.C]	HLR245	63	14	17	82%	3.7
CBBO	[C.I.C]	LG4C	56	30	42	71%	1.3

Table 3: ZA and ZK Notifications per CB (Proposed Replacement) by Manufacturer and model 2020-mid 2025

Table 3 above highlights specific makes and models proposed for replacement under TRR 27–32.

The [C.I.C] 500kV circuit breakers, the first generation of CBLT, have recorded issues on every unit (100%). These issues primarily include hydraulic failures, flange corrosion, SF6 gas leaks, and deterioration of control components. In 2008, circuit breakers of this type at HWTS and LYPS underwent mechanism and OEM led interrupter refurbishments, which extended their service life by approximately 15 years. These refurbishments largely addressed hydraulic fluid and SF6 leak issues. However, concerns have emerged regarding the suitability of the replacement hydraulic seals used during refurbishment. Specifically, premature damage to a hydraulic seal was identified on the LYPS 2 Bus 4 circuit breaker in 2020. Given the potential for similar failures across the entire fleet of refurbished breakers, AusNet began the replacement of the highest risk [C.I.C] circuit breakers in the 2017-2022 TRR period. Reliability continues to be poor and replacement of the remaining units is proposed as a major replacement project at HWTS and LYPS to mitigate the risks associated with these high-consequence location.

For the CBMO fleet, the [C.I.C] 220kV circuit breakers have been identified as a priority for replacement due to widespread and recurring issues, including mechanism-related failures and flange corrosion. Approximately 82% of units of this type have recorded notifications, with an average of 3.7 notifications per unit. Nearly double the CBMO fleet average of 1.89 and more than five times higher than the new CBDT average of 0.71. For HLR84 66kV CBs, this type has also shown reliability concerns, particularly with their interrupters. Common issues include reduced pressure in the head due to nitrogen leaks, oil gauge failures, and age-related physical deterioration. These faults are difficult to detect and monitor, as no condition monitoring or any alarming devices are available. While the average notification rate for HLR84 is lower at 1.4, it still exceeds twice the CBDT average.

In addition, the [C.I.C] 66kV circuit breakers are typically paired with 66kV standalone Modern Product current transformers (CTs), which have also been identified as problematic. Several CTs have shown signs of insulation oil deterioration, as indicated by DGA results. This degradation is primarily driven by elevated moisture levels within the oil system, resulting from ineffective sealing and negative internal pressure under certain atmospheric and loading conditions. Due to the combined reliability concerns of both the [C.I.C] breakers and associated CTs, AusNet has proposed a terminal station replacement project at MWTS, aiming to replace all affected circuit breakers with their associated CTs with modern dead tank circuit breakers featuring integrated CTs, thereby improving reliability.

The [C.I.C] 66kV circuit breakers is a bulk oil circuit breaker containing approximately 1,000 litres of insulating oil. These units are typically installed without containment systems for oil spills, which poses a significant environmental risk in the event of major failures or routine leaks. Additionally, the [C.I.C] breakers present notable health and safety concerns due to their large physical dimensions and maintenance-intensive design. In November 2023, a serious incident occurred involving an [C.I.C] unit in service. One of its 66kV porcelain bushings experienced a catastrophic failure. Although the average number of notifications per breaker over the past five years is only 1.3, likely due to the absence of online monitoring devices. Most [C.I.C] circuit breakers have already been progressively replaced and through current replacement projects at terminal stations such as [C.I.C]. The remaining units are scheduled for replacement under TRR 27–32.

All models listed in Table 3 are now considered technically obsolete, with no more OEM support available and very limited refurbishment opportunities. Consequently, spare parts can only be sourced from decommissioned units, which significantly complicates maintenance and increases operational risk. These factors strongly support the case for targeted replacement.

Table 4 below presents transmission circuit breakers categorised by voltage class, along with associated notification metrics. Notably, the 275 kV breakers exhibit an average of 7.2 notifications per breaker, significantly higher than other voltage classes. However, approximately two-thirds of these notifications are related to SF6 gas leaks, which require frequent top ups. In contrast, the 66 kV and 220 kV breakers show much lower notification rates 1.17 and 1.34 per breaker respectively, primarily because most are newer dead tank designs. The 500 kV breakers, of which 40% are [C.I.C] and [C.I.C] models, average 3.66 notifications per breaker, largely driven by issues with their hydraulic mechanism systems and SF6 leaks. All [C.I.C] circuit breakers are currently being replaced in the current period in terminal station replacement project at MLTS.

NOMINAL VOLTAGE (kV)	Number of Notifications	Number of CB with Notifications	Total CB Population	Percentage of CB Notifications Rate	Average Notification per CB
500	249	42	68	62%	3.66
330	45	14	29	48%	1.55
275	36	4	5	80%	7.20
220	516	154	384	40%	1.34
66	545	217	465	47%	1.17
22	28	10	60	17%	0.47

Table 4: ZA and ZK Notifications by operating voltage

4.2. Major Asset Failures

Appendix 1 displays the quantity of significant defects and failures related to transmission circuit breakers from 2000 to mid-2025 that necessitated either total replacement or the replacement of a major component. Aside from the safety implications, major failures or defects can result in extended duration outages and deplete critical spares holding especially the older circuit breakers which are obsolete. Major failures associated with individual assets can in some cases be the precursor to similar failures on other assets of the same model. Therefore, observing close attention to causal factors and proactively implementing remedial measures on remaining assets can help minimise the impact of trending behaviours and improve equipment reliability.

Figure 11 illustrates the average circuit breaker (CB) failure rates by technology and age group, excluding high-operation CBs. The data exhibits a typical bathtub curve pattern characterised by early-life failures, followed by a stable and reliable period, and then a gradual increase in failures beyond 30 years of age. After 45 years, failure rates begin to flatten out, largely due to targeted replacement programs that have removed the poorest-condition and highest-risk CB types. From the chart, it is evident that CBBO, CBMO and the first-generation 500kV CBLT have the highest historical failure rates. This suggests these CB types are approaching end-of-life and experiencing elevated failure risks. In response, AusNet has prioritised replacement efforts for CBBO [C .I C] and the first-generation CBMO [C . I . C] to mitigate the risk of major failures. All these types have experienced a Major failure and impacted the network in the last 5 years.

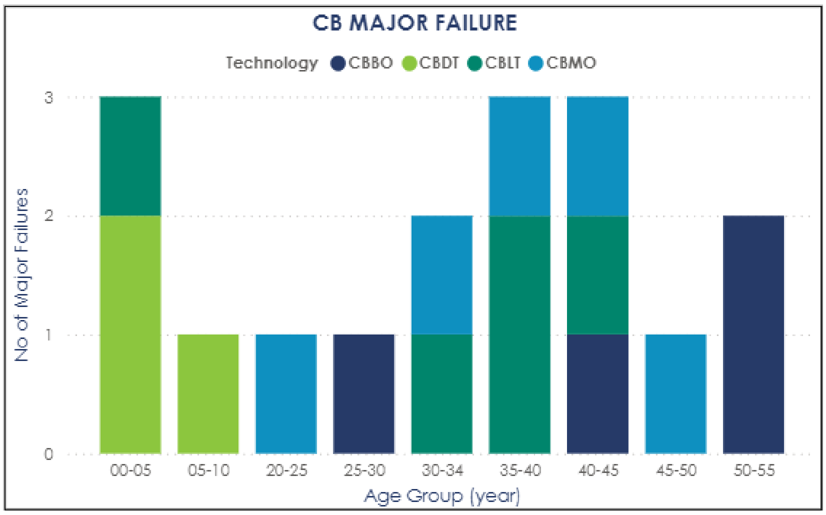

Figure 11: CB major failures by technology and service age (low operating CBs)

4.3. High Operation Circuit Breakers

Most circuit breakers operate infrequently, typically fewer than 10 times per year. However, circuit breakers used for capacitor banks, shunt reactors, and certain generator connections experience significantly higher switching frequencies compared to those used for feeders, buses, or transformers. This is due to their role in voltage regulation and generation support.

Capacitor bank circuit breakers are exposed to pre-strike and high inrush currents during switching because of the capacitive nature of the load. Shunt reactor breakers, on the other hand, are prone to restrikes during opening operations due to the steep transient recovery voltage associated with reactive load switching. Given the demanding electrical switching duties involved in capacitor bank and shunt reactor applications, contact wear is accelerated. As a result, manufacturers typically reduce the rated number of allowable electrical operations (wear out limit) often by half for these types of breakers to account for the increased stress and wear.

4.3.1. Population and Failure

There is a total population of 73 Capacitor Bank CBs,14 Shunt Reactor CBs and 2 high operation Generator CBs (EPSY) in the regulated asset base as of 22 Sep 2025, and it is evident from the Major failure list in appendix 1, that capacitor bank CBs have a much higher relative major failure rate than other applications, predominantly due to electrical and mechanical wear out from high operations counts. This is also shown in Figure 12 below. In most cases these failures occur on CBs with very high operating counts, which typically are approaching their design limits, despite being relatively young. This suggests that operational frequency, rather than longer term age/exposure related deterioration mechanisms, is the dominant factor influencing reliability in these assets.

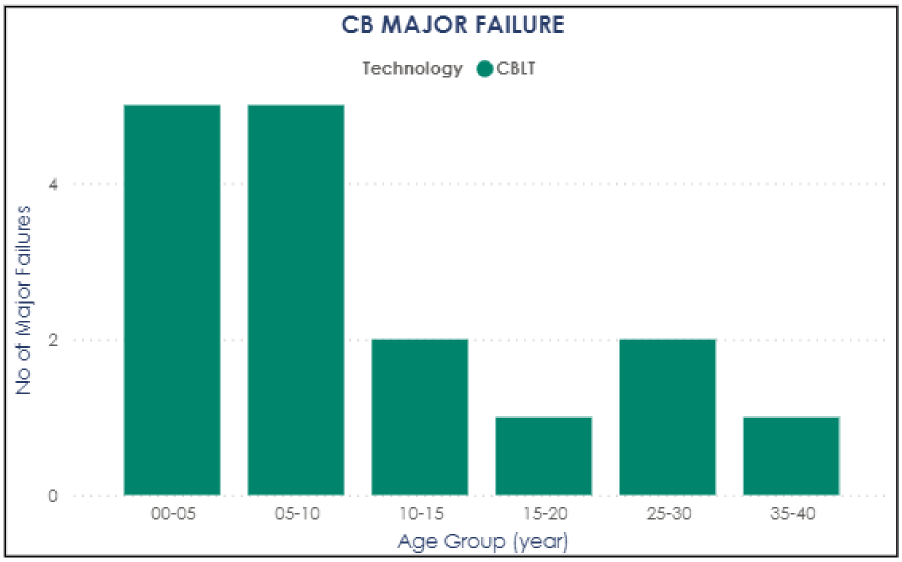

Figure 12: CB failures by technology and service age (High operating CBs)

4.3.2. Operation Frequency

Operational frequency analysis in figure 13 shows approximately 20% of the fleet are in the high operation categories > 100 operations per year, and 5% in the very high operation category of over 300 per year. In this high operation category, CBs are wearing out in 15 to 30 years range, and in latter very high category even a modern circuit breaker would reach wear out limits within 10 – 20 years.

However, it has been observed that the number of operations for some high-duty circuit breakers has slightly declined over the past three years. This trend may be attributed to several factors, including changes in load and generation profiles, as well as modifications to network configuration and operational strategies.

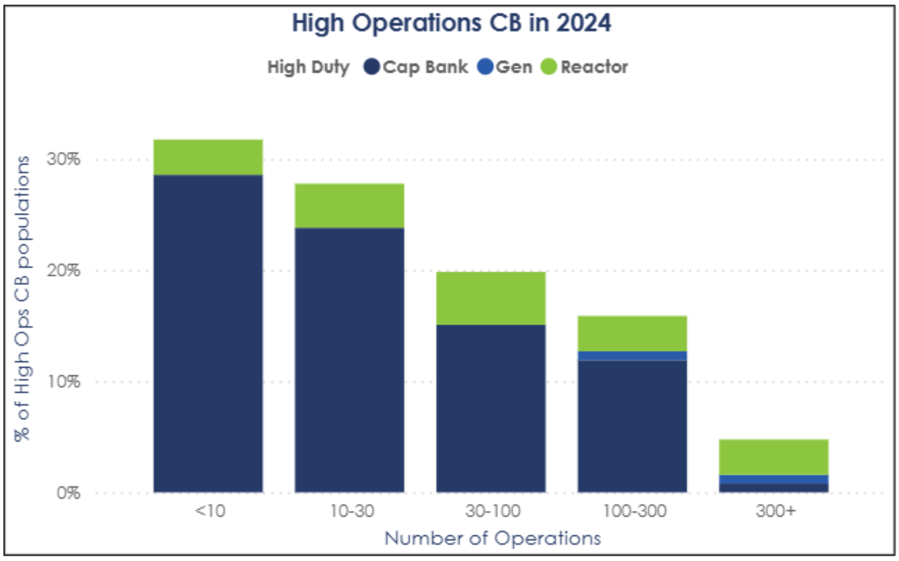

Figure 13: Capacitor bank, Generation & Shunt Reactor CB operation graph in 2024

4.3.3. Replacement and Refurbishment

Due to high operational demands and heavy-duty applications, the effective operational life of high operation circuit breakers is significantly reduced. AusNet manages these CBs nearing their operational limits through below two main strategies:

- Refurbishment – typically practice, when the breaker type has been reliable in its application and still supported by the OEM [C . I . C]
- Replacement – Applied when the breaker is technically obsolete and no longer supported by the OEM [C . I . C] and specifically unreliable and reduced limited operation ([C . I . C] reduced by manufacturer after major failures), previous major failure history [C . I . C] for generator switching application)

Figure 14 below illustrates the number of high operation circuit breakers and their forecasted year of reaching the wear out limit before 2037, as defined by AusNet and the manufacturer. There are [C . I . C] operation CBs are expected to reach the limit before 2030, and another 6 between 2033 and 2036 based on current usage driven by AEMO or Customer requirements. The proposed program through asset replacement and major station replacement program for the 2027-32 period addresses these high operated circuit breakers that have reached their limit [C . I . C] and complimented with a circuit breaker OPEX refurbishment program for OEM supported types.

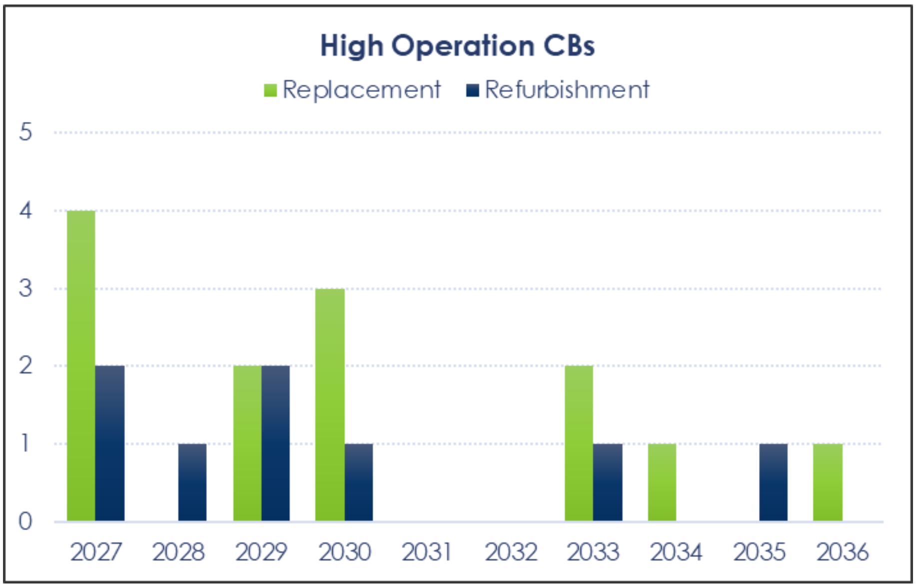

Figure 14: Capacitor bank, Generation & Shunt Reactor CB wear out limit forecast

4.4. Performance Summary

Based on the series of charts and discussions, the overall performance of circuit breakers (CBs) within the network reveals several key trends. Notifications have steadily increased from 2020 to mid-2025, with CBLT and CBDT object type, and voltage levels such as 220kV and 66kV, consistently contributing the most notifications due to the CBBO & CBMO type CBs with higher failure risk have been progressively replaced through several TRR periods. Defect types such as Broken, Failure, and Fault dominate the notification landscape, while component-level analysis highlights recurring issues in bushings, control boxes, and electrical connections.

The chart on major failures associated with high operation CBs, shows that newer CBs (0–10 years) experience more frequent major failures, which taper off with age, though a mid-life spike (25–30 years) is observed. The first 5 years may be classed 'early bathtub' failures and are covered by manufacturers warranties, so they are immaterial. The 5-10 year failure rates indicate that not all systemic issues are resolved by the end of the warranty period, but while CBs are actively monitored and issues are increasingly detected and repaired, so that there's a tendency for failure rates to stabilise over time. These findings support the need for targeted early-life interventions and mid-life reviews to maintain network reliability.

Performance data are key inputs into our asset health assessment and its risk model, enabling quantification of failure risks across various circuit breaker types, voltage levels, defect categories, and component parts. By integrating these insights, we gain a deeper understanding of asset health and performance trends, which in turn supports more accurate forecasting and prioritisation of investment decisions. The asset health assessment will be discussed in Section 5, and the modelling approach and its application are detailed in Section 7.

5. Asset Health

The asset health condition is illustrated by the likelihood of failure profile derived from the data and insights presented in Section 4 Asset Performance of this document, specifically within the performance analysis. The following graphs illustrate the likelihood of failure profiles from multiple perspectives, including object type, voltage level, and asset age, and the likelihood score reflects the probability of failure, with 1 being the least likely and 5 being the most. REF: AMS 01-09 Section 5.4 for detail. By examining these dimensions, we can obtain a comprehensive view of the asset health condition and the associated program of work proposed.

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

Table 5: Likelihood Scale

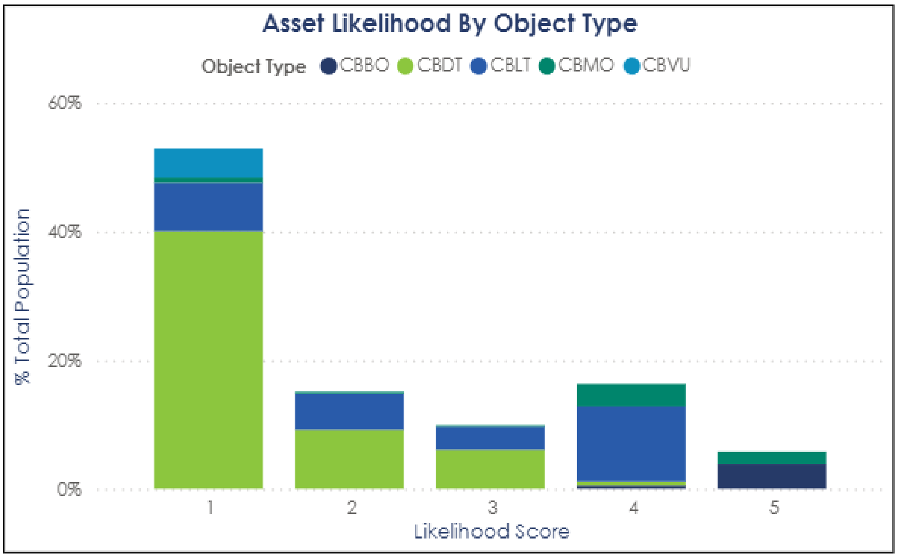

Figure 15: CB Likelihood Score by Object Type

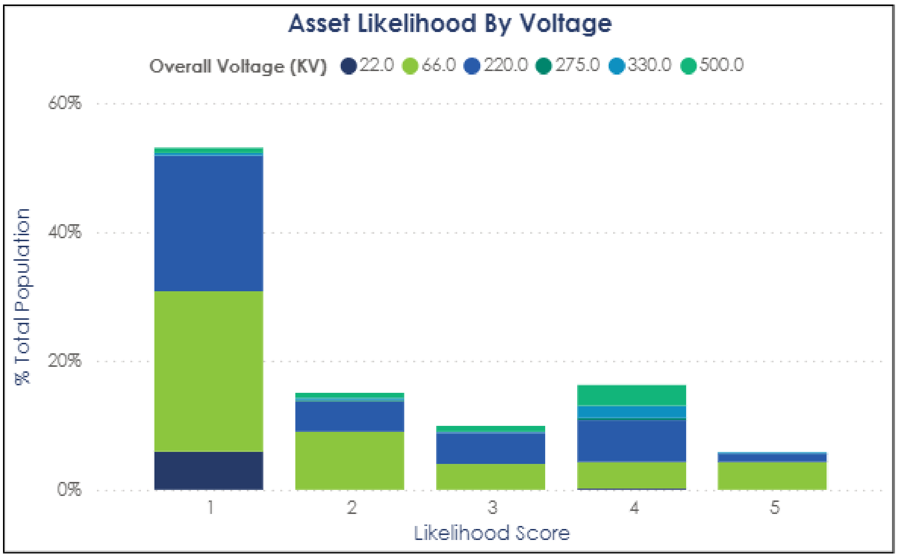

Figure 16: CB Likelihood Score by Voltage Class

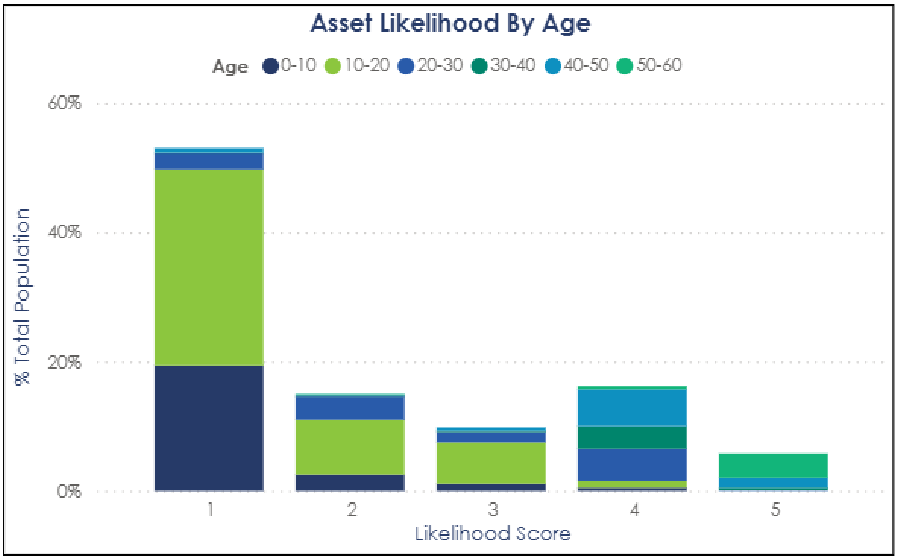

Figure 17: CB Likelihood Score by Age Profile

Key Findings on Asset Health Conditions Derived from the Figures above:

- Nearly all units, along with several underperforming CBMO currently carry a likelihood score of 5, indicating a high risk of failure. [C . I . C] circuit breakers, which fall under the CBBO category and are equipped with porcelain bushings, pose a risk of catastrophic failure, potentially endangering both assets and personnel in proximity. Furthermore, these breakers are fully obsolete and no longer supported by any original equipment manufacturer (OEM), compounding the operational and maintenance challenges. Major station rebuild at TTS and asset replacement at FTS, GNTS and HOTS are proposed to replace these high risk bulk oil breakers before [C . I . C]
- The remaining CBMO units and certain older vintages of 500kV have a likelihood score of 4, indicating elevated failure risk and signalling that these circuit breakers are nearing end-of-life. The [C.I.C] 220kV and HPL breakers, classified CBMO and CBLT respectively, have experienced repeated failures due to mechanism-related issues. These units are fully obsolete with limited OEM support. A replacement program was initiated in previous TRR periods to recover mechanisms for refurbishment and extend asset life. Continuation of this program is required for TRR 27–32.
- Similarly, the same replacement strategy has been applied to the 330kV [C.I.C] minimum oil circuit breakers, as well as the [C.I.C] 500kV units, which fall under the CBMO and the older vintages of CBLT category, respectively. These assets are scheduled for replacement as part of a major station upgrade program, continuing the momentum of previous replacement initiatives.

- It has been observed that several high-operation circuit breakers which are the CBLT type, have a likelihood score of 3 or lower. Due to their high frequency of operation and the limits defined by the original manufacturers, these CBs are subject to a sharp increase in failure rate once those limits are reached. Consequently, for CBs that have exceeded their operational thresholds as identified in TRR 27–32, and refurbishment is no longer a viable option, they have therefore been earmarked for replacement.

6. Related Matters

6.1. PCB in Bulk Oil and Minimum Oil Circuit Breakers

Older 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.

6.2. Asbestos in Older Oil Circuit Breakers

Asbestos containing material are found in older bulk oil circuit breakers such as 66kV [C.I.C] circuit breakers in arc chutes, 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 must be adopted when it is required to modify or removing asbestos as per HSP 05-05 guideline.

6.3. Technical Obsolescence / Spares Management

Manufacturers generally cease to formally support when CB designs are older and availability of OEM spares parts is phased out. Typically, the phasing out of support coincides with an equipment's 'Design Life', which is typically 30 years, with spare parts no longer available around 35 years. Similarly, the specialist knowledge and ability of the manufacturer to overhaul / refurbish their circuit breakers will also diminish over a similar timescale. Some original OEM no longer have a presence or extremely limited service capability within Australia.

Serviceability and therefore operational life expectancy can be improved midway through asset operational life, by increasing the level of spares held in stores just before the OEM ceases manufacture. From approximately 35 years to 40 years, stores holding will deplete to the point that by 45 years, 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.

The 40-45 year upper limit for operational life applies to modern switchgear, which is constructed in modular form and is heavily reliant on custom OEM spare part assemblies. This contrasts with earlier CBBO designs, which in part were more robust, but also were suitable for parts to be re-manufactured at a subcomponent level. The older philosophy allowed early CB designs to enjoy a longer service life than the modern designs, potentially 50 years or more. However, they are disadvantaged with lower reliability and more frequent maintenance intervals. Industry-wide quests for lower capital cost, improved reliability and extended maintenance intervals have justified the transition to modular designs, but this infers a cap to lifecycle, since obsolescence is more pronounced.

Regarding bulk oil and minimum oil circuit breakers, they are fully obsolete and no longer supported by any OEM. Availability of spare parts is reliant on potentially sub-standard, re-manufactured/copied parts sourced from the open market. The utilisation of copied components can be expected to further impact reliability and AusNet's risk analysis process highlights tolerable limits. Ultimately, bushings on AusNet's fleet of CBBOs have reached their maximum lifespan. The limited availability of usable spare bushings and uneconomic cost of new replacements has become the limiting factor that drives today's priority replacement.

6.4. 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. Oil Circuit breakers built in 1960s are generally maintenance intensive and lower operating duty compared to modern 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.

7. Proposed Program of Work

7.1. Approach

7.1.1. Risk

AusNet's asset management decisions within the transmission network are guided by a risk-based approach, ensuring alignment with our organisational risk appetite. For circuit breakers, risk treatment required to achieve this over time involves replacement & maintenance activities. Justification for these projects are developed based on current risk and extrapolated risk.

The risk of each asset is calculated as the product of Probably of Failure (PoF) of the asset and the Consequence of Failure (CoF). This risk is then extrapolated into the future accounting for forecast changes in PoF and CoF.

AusNet's approach to asset risk management is detailed in REF: AMS 01-09 Asset Risk Assessment Overview.

7.1.1.1. Asset Risk Quantification Methods

Probability of Failure

The probability of failure (PoF) for circuit breakers is calculated using a trained machine learning system that leverages real data from AusNet's asset management system. This enables a more robust, data-driven approach that reduces reliance on engineering rules derived solely by subject matter experts (SMEs).

The system generates a one-year-ahead forecast, calibrated against recent actual volumes of ZK and ZA notifications, ensuring alignment with observed intervention rates. Future-year PoF forecasts are extrapolated from the base-year forecast using Weibull parameters established by AusNet. For a detailed explanation of the methodology, refer to AMS 01-09.

The model is trained by identifying correlations between failure events and circuit breaker characteristics and measurements, often reflecting insights that SMEs would intuitively derive. These correlations and model outputs are reviewed by SMEs to support reliability and trust before any decisions or actions are taken.

The model specifically incorporates:

- ZK fault notifications
- Urgent ZA corrective maintenance notifications, including:
  - Defects requiring action within <30 days for CBLT and CBDT
  - Defects requiring action within <90 days for CBBO and CBMO

Dedicated models are developed for each of the key circuit breaker components and their respective notification types:

- Insulation
- Operating Mechanism/Drive
- Auxiliary Systems (e.g., electrical control and connections)

The overall PoF for a single circuit breaker is a calculated as a weighted combination of the three component-level models.

Bulk oil circuit breakers (CBBOs) require an additional tailored modelling approach due to their unique design. CBBOs are the only type that contain graded bushings, which are non-maintainable components and have been identified as a primary driver for replacement decisions across the CBBO fleet.

To address this, AusNet applies a dedicated health score to circuit breaker bushings. This score is derived from electrical testing data and is used to calculate the bushing-specific PoF. The bushing PoF is then combined with the model derived PoF for the rest of the CB to produce a single PoF for each CBBO.

This modelling approach captures all relevant failure modes are captured particularly for components like bushings that may not be adequately represented in other models alone.

Consequence of Failure

AusNet assigns a monetised value to CoF which provides an economic basis of calculating potential consequence.

The cost of failure is assessed through key lenses: Safety, Environment, Customer/Market Impact and Financial consequences. These lenses provide a structured view of the potential impacts, resulting in loss of energy supply, injury to employees or members of the public, or environmental hazards. Table 8 summarises the focus of each lens:

CONSEQUENCE LENSES	DESCRIPTION
Safety	Threat to health and safety of people
Environment	Fire/smoke damage Oil Spills Sulphur hexafluoride (SF_6) uncontrolled discharge
Customer / Market	Loss of Supply to Customers Impact on energy market
Financial	Asset/Component replacement costs Collateral damage Emergency response

Table 6: Consequence lens description

7.2. Economic Viability

7.2.1. Economic Model

AusNet use the calculated risk based on PoF and CoF outputs to identify optimal intervention years, balancing technical feasibility with economic efficiency. These outputs are incorporated into an economic model. The economic model demonstrates the year when the calculated annualised risk is higher than the annualised replacement cost, and as such when the asset becomes economically viable to replace. The concept is shown visually in Figure 18 below.

The economic model is producing a structured approach for each asset in the fleet. The economic model for the justified replacement program is available in asset class economic model: Asset class economic models REF: ANT – TRR 2027-32 Asset Replacement Economic Model – Circuit breakers, Disconnector & Earth switch combine – Final

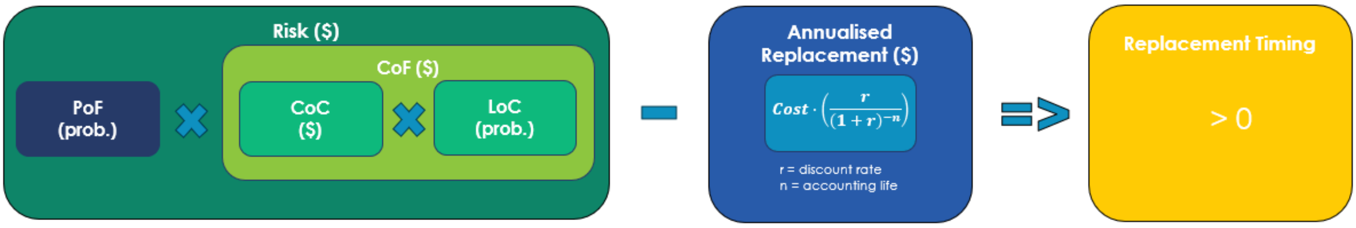

Figure 18: Viability Calculations

7.3. Engineering Validation

Following the generation of asset health predictions by AusNet's advanced statistical models and Weibull forecasts, a structured validation process is undertaken. This step enables model outputs to be interpreted within the broader context of engineering judgement, operational experience, and current asset condition data.

Assessment as to whether the model's recommendations such as asset replacement, refurbishment or no action are reasonably practicable. This involves verifying condition data, evaluating operational priorities, and considering strategic timing of interventions. Where appropriate, recommendation can provide alternative actions based on their professional assessment.

This validation process complements the use of Weibull-based forecasts by integrating predictive outputs with expert knowledge. It supports a balanced and accountable approach to asset management, one that upholds technical integrity while remaining responsive to operational realities.

7.4. Proposed Program

The AusNet modelling process transforms CB asset performance analysis into economic assessment. The confluence of this in conjunction with risk models promotes a limited number of CBs for prioritised replacements.

In general, the most significant asset types requiring replacement through TRR 2027-32 are:

- 66kV [C.I.C] Bulk oil circuit Breakers
- One remaining 22kV [C.I.C] Bulk oil circuit breakers
- 220kV [C.I.C] Minimum Oil circuit breakers
- [C.I.C] CBs (exceeding max ops and not suitable for refurbishment)
- 66kV [C.I.C] Minimum Oil CBs (part of major station program)
- 330kV [C.I.C] Oil circuit breakers (part of major station program)
- 500kV [C.I.C] (part of major station program)

It is important to note that the majority of the circuit breakers (CBs) types listed above are part of ongoing fleet replacement programs. These replacements are planned to occur progressively across multiple TRR periods. The majority have also had a life extension refurbishment program applied while OEM support existed. For instance, approximately 20 years ago, there were over 200 [C.I.C] installed across the AusNet network. Due to health and safety concerns related to failure risks, a targeted replacement program was initiated. High-risk CBs were prioritised for replacement, while a bushing testing and replacement program was implemented to extend the life of the remaining units by addressing defective bushings, and using the better bushings salvaged from ongoing replacement program projects. The final 15 [C.I.C] CBs are scheduled for replacement during TRR periods 27 to 32.

A similar approach has been taken with the 220kV [C.I.C] Minimum Oil Circuit Breakers fleet, where 11 units are planned for replacement under TRR2027–2032. In the last decade, a replacement program targeting the high-risk 220kV [C.I.C] units was undertaken with some recovery of unavailable spares and a refurbish/ retune program was undertaken with the OEM on the remaining fleet. The reliability has decreased, and the equipment type is now considered obsolete. Replacement of the remaining line circuit breakers has been proposed. The decommissioned breakers will serve as a source of (currently unavailable) spare parts for the remaining 7 x [C.I.C] units at YPS, used for generator and auxiliary transformer switching. These remaining circuit breakers will be closely monitored and eventually retired at the planned closure of Yallourn Power Station in the 2027-32 period.

Additionally, 35% of the 66kV [C.I.C] Minimum oil circuit breakers and their associated high-risk Modern Product CTs are scheduled for replacement before 2032. The 66kV [C.I.C] were also subject to a significant refurbish/ retune program with the OEM over a decade ago to extend their life. AusNet also plans to initiate Stage 2 replacement of the remaining units after 2032.

AusNet major station strategy considers the condition of circuit breakers, their adjacent instrument transformers and associated disconnectors/earth switches. Therefore, there are some cases where the economics associated with combined replacement tip the balance towards replacement on otherwise borderline cases for each of these asset types.

Refer to Appendix 2 for details of the CB replacement list under the asset replacement program.

8. Asset Strategies

The following section summarises the strategies. The itemised program of work for circuit breakers is presented in Appendix 2.

8.1. New Installations

- Specify outdoor SF6 insulated dead tank/ polymer insulator circuit breakers up to 220kV and Live tank / polymer insulator circuit breakers for 275kV and above for replacement in outdoor terminal stations.
- Specify SF6 insulated circuit breaker for 66kV and above voltages in Gas insulated switchgear (GIS)
- Specify indoor metal clad /arc fault rated vacuum interrupter or SF6 insulated circuit breaker in indoor modular AIS or GIS for 22 kV indoor installations.

8.2. Condition Monitoring

- Continue visual checks of circuit breakers as part of the regular terminal station inspections.
- Continue annual non-invasive condition monitoring scans including the use of radio frequency interference, ultrasonic, infra-red thermal and UV corona camera testing to evaluate the integrity of circuit breaker insulation and external and internal connections.
- Continue to monitor the bulk oil CBs SRBP bushing condition through electrical testing program

8.3. Maintenance

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

8.4. Spares Holding

- Maintain strategic spares holding of CBs as per spare holding policies
- Consider opportunities for dynamic spares holding as assets tend towards manufacturing obsolescence
- Continue to salvage best parts and complete assemblies of obsolete CB to achieve per spare holding policies

8.5. Refurbishment

- Use bushing replacements to manage shorter term risk for from the very poor condition bushings of CBBOs, as identified in the electrical testing/condition monitoring program (limited to availability of acceptable bushings released from ex-service fleet)
- Complete refurbishment programs for [C.I.C] 220kV CB mechanisms during TRR 2027-2032 period
- Where practicable, refurbish [C.I.C] 66kV LTB high operation CBs during TRR 2027-2032 period
- Continue to refurbish/ repair SF6 leaks in live LTCBs and GIS where economical
- Monitor the earliest installed DTCB's for gas leakage trends.

8.6. Replacement

- Asset Replacement program and major station replacement program (external to this document) have been proposed to replace the high-risk CBs to manage failure risks effectively while maximising their operational lifespan by refurbishment program.
- Refer to Appendix 2 for details of the CB replacement list under the asset replacement program.

9. Resource References

No.	TITLE
1	AMS 01-05 Strategic Asset Management Plan
2	AMS 01-09 Asset Risk Assessment Overview
3	HSP 05-05 guideline: Asbestos Management
4	HSP 05-32 guideline: PCB Management
5	ANT – TRR 2027-32 Asset Replacement Economic Model – Circuit breakers, Disconnector & Earth switch combine – Final

10. Schedule of Revisions

ISSUE NUMBER	DATE	DESCRIPTION	AUTHOR	APPROVED BY
5	21/11/06	Editorial review.	[C.I.C]	[C.I.C]
6	15/02/07	Review and update.	[C.I.C]	[C.I.C]
7	17/03/07	Editorial review.	[C.I.C]	[C.I.C]
7.1	19/10/12	Revised Structure and General update.	[C.I.C]	[C.I.C]
8	07/02/13	Editorial review.	[C.I.C]	[C.I.C]
9	22/07/15	Review and update.	[C.I.C]	[C.I.C]
10	17/09/2020	Review and update	[C.I.C]	[C.I.C]
11	30/08/2025	Review and update	[C.I.C]	[C.I.C]

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Appendices

Appendix 1 – Circuit Breaker Major Failure since 2000

Incident Date	Station	kV	CB Manuf.	CB Designation	Technology	Duty	Age (years) at time of failure	Nature of Failure	Remedial Action
7/02/2001	ROTS	220	[C.I.C]	[C.I.C]	Bulk oil	Transf./Line/ Bus Tie	28	High Resistance joint developed internal to bushing head causing significant overheating.	Replaced bushing.
1/03/2001	HWPS	220	[C.I.C]	[C.I.C]	Bulk oil	Transf./Line/ Bus Tie	30	High Resistance joint developed internal to bushing head causing significant overheating.	Replaced bushing.
29/07/2001	TTS	220	[C.I.C]	[C.I.C]	Bulk oil	Transf./Line/ Bus Tie	27	Electrical testing indicated unacceptable internal insulation integrity and could not be returned to service.	Replaced bushing.
3/09/2001	TTS	220	[C.I.C]	[C.I.C]	Bulk oil	Transf./Line/ Bus Tie	27	Bushing explosion with collateral damage.	Replaced failed and damaged bushings. Established bushing oil sampling regime as part of Class 2 maintenance for fleet.
10/10/2002	SYTS	500	[C.I.C]	[C.I.C]	SF_6 – DT or GIS	Transf./Line/ Bus Tie	19	Partial closure due to loose drive rod nut causing half interrupters not to engage.	Replace Interrupter assembly
4/02/2003	SYTS	500	[C.I.C]	[C.I.C]	SF_6 – DT or GIS	Transf./Line/ Bus Tie	20	During operation, a flashover to tank occurred due to loose contact fingers falling out.	Replace Interrupter assembly.

Incident Date	Station	kV	CB Manuf.	CB Designation	Technology	Duty	Age (years) at time of failure	Nature of Failure	Remedial Action
14/03/2003	SHTS	66	[C.I.C]	[C.I.C]	SF_6 – Live tank	Transf./Line/ Bus Tie	3	Catastrophic failure while attempting to clear a downstream fault. Investigations revealed TRV exceeded CB capability.	Complete CB replaced with same type. All similar CB on transformer bays fitted with 26nF surge capacitors to reduce TRV.
11/06/2003	SMTS	500	[C.I.C]	[C.I.C]	SF_6 – DT or GIS	Transf./Line/ Bus Tie	22	Partial closure due to interrupter nozzle fracture blocking the operation.	Replace Interrupter assembly.
23/07/2004	SMTS	500	[C.I.C]	[C.I.C]	SF_6 – DT or GIS	Transf./Line/ Bus Tie	23	During X ray inspections to check for nozzle problems found a broken drive rod at the 4th interrupter stage. The interrupter was wedged close. This CB was only operating 3 out of 4 interrupters.	Replace Interrupter assembly.
4/10/2004	SYTS	500	[C.I.C]	[C.I.C]	SF_6 – DT or GIS	Transf./Line/ Bus Tie	21	During open operation a flashover to the tank occurred. Possibly particles contamination. Only 18 months since refurbishment by OEM.	Replace Interrupter assembly.
12/05/2005	EPSY	220	[C.I.C]	[C.I.C]	SF_6 – Live tank	Generator	1	Catastrophic failure during opening operation to offload Generator.	Complete CB replaced. Investigations could find no obvious cause.
14/08/2005	RWTS	66	[C.I.C]	[C.I.C]	Minimum Oil	Transf./Line/ Bus Tie	45	Catastrophic failure during trip operation. Investigations suspected a wear out failure.	Complete CB replaced with same type. Remaining OS10 on network programmed for replacement.
28/08/2006	DDTS	220	[C.I.C]	[C.I.C]	SF_6 – Live tank	Cap Bank	4	Mechanism failure with broken component parts during close operation. CB switches a Cap Bank.	Complete mechanism replaced.

Incident Date	Station	kV	CB Manuf.	CB Designation	Technology	Duty	Age (years) at time of failure	Nature of Failure	Remedial Action
10/10/2006	ERTS	66	[C.I.C]	[C.I.C]	SF_6 – Live tank	Cap Bank	11	Catastrophic failure during opening operation. Investigations revealed an early wear out failure at 2400 operations.	Complete CB replaced. Policy change and Operation limit for type reduced to 1800 operations.
22/08/2007	BETS	66	[C.I.C]	[C.I.C]	SF_6 – DT or GIS	Transf./Line/ Bus Tie	1	Flashover to tank during close operation to energise line. Flashover on line side of CB. Most likely particle contamination.	Complete CB replaced.
29/12/2007	MLTS	220	[C.I.C]	[C.I.C]	SF_6 – Live tank	Cap Bank	6	Mechanism failure with broken component parts on No. 2 cap bank CB during close operation. CB was a high operation Some suspected interrupter damage due to internal arcing.	Complete CB replaced with same type. Integrity of the fleet of same type checked by ABB.
10/04/2008	TGTS	66	[C.I.C]	[C.I.C]	SF_6 – Live tank	Cap Bank	1	Catastrophic failure during opening operation to de-energise Cap Bank. Investigations revealed incorrect factory mechanical setup.	Complete CB replaced. All CB manufactured by Indian factory (approx. half the fleet) recalled and interrupters replaced. Revised earth fault protection settings applied to all Cap Banks to detect this failure mode.
14/08/2008	TBTS	66	[C.I.C]	[C.I.C]	SF_6 – Live tank	Cap Bank	6	Mechanism seized and failed to close. 1600 operations.	Complete CB replaced. SMI updated to incorporate further mechanism instructions and warnings.
10/10/2008	BATS	66	[C.I.C]	[C.I.C]	SF_6 – Live tank	Cap Bank	4	Mechanism seized, and could not operate. Investigations suspected	Complete CB replaced. SMI updated to incorporate further mechanism instructions and warnings.

Incident Date	Station	kV	CB Manuf.	CB Designation	Technology	Duty	Age (years) at time of failure	Nature of Failure	Remedial Action
								accidental overcharging during maintenance.	
11/12/2008	MWTS	66	[C.I.C]	[C.I.C]	Minimum Oil	Transf./Line/ Bus Tie	25	Mechanism components broken and frame damaged.	Complete mechanism replaced.
5/04/2009	MWTS	66	[C.I.C]	[C.I.C]	Bulk oil	Transf./Line/ Bus Tie	41	Burn out of solenoid mechanism.	Complete mechanism replaced.
7/04/2009	MWTS	66	[C.I.C]	[C.I.C]	Bulk oil	Transf./Line/ Bus Tie	41	Internal Flashover on Wph (MFA feeder) during clearing a downstream fault. Suspected interrupter wears out failure.	Complete CB replaced.
29/10/2009	RTS	66	[C.I.C]	[C.I.C]	Minimum Oil	Transf./Line/ Bus Tie	40	Catastrophic failure during trip operation. Investigations suspected a combination of wear out and evolving fault conditions.	Complete CB replaced with same type. Remaining HKEY at RTS programmed for replacement.
12/12/2009	SMTS	220	[C.I.C]	[C.I.C]	SF_6 – DT or GIS	Transf./Line/ Bus Tie	1	Flashover to tank at mechanism support insulator end while CB open. Possible particles contamination.	Complete CB replaced.
9/06/2010	GTS	66	[C.I.C]	[C.I.C]	SF_6 – Live tank	Cap Bank	10	Wear out failure at 1830 operations (compared to internal revised limit of 1800 operations).	Complete CB replaced. Policy changes and Operation limit for type reduced to 1000 operations.
9/11/2010	TSTS	66	[C.I.C]	[C.I.C]	SF_6 – Live tank	Cap Bank	8	Failure to clear current during opening operation to de-energise Cap Bank. Bus protection operated. Later	Complete CB replaced.

Incident Date	Station	kV	CB Manuf.	CB Designation	Technology	Duty	Age (years) at time of failure	Nature of Failure	Remedial Action
								investigations could find no root cause. Approx 1600 operations	
14/12/2010	SVTS	220	[C.I.C]	[C.I.C]	Minimum Oil	Transf./Line/ Bus Tie	44	Partial close operation. Drive insulators flange mortar crumbled.	Replaced broken drive insulators.
20/12/2010	KTS	66	[C.I.C]	[C.I.C]	SF_6 – Live tank	Cap Bank	10	Wear out and slack internal drive rod. CB had performed 1500ops.	Complete CB replaced.
28/12/2010	HWPS	220	[C.I.C]	[C.I.C]	SF_6 – DT or GIS	Generator	6	Extreme TRV and DC offsets have exceeded CB capability.	Complete CB replaced.
25/03/2011	WMTS	66	[C.I.C]	[C.I.C]	SF_6 – Live tank	Cap Bank	16	Extreme SF_6 leak developed quickly requiring weekly top ups.	Complete CB replaced.
1/04/2011	HTS	66	[C.I.C]	[C.I.C]	SF_6 – Live tank	Cap Bank	14	Mechanism components broke	Complete mechanism replaced.
29/07/2011	TTS	220	[C.I.C]	[C.I.C]	SF_6 – Live tank	Cap Bank	10	High SO2, a by-product of excessive arcing. Loose interphase linkages due to lack of locking washers. Later internal investigation found damaged nozzle.	Complete CB replaced.
30/09/2011	YPS	220	[C.I.C]	[C.I.C]	Minimum Oil	Transf./Line/ Bus Tie	32	Mechanism failed and broken parts due to sticking mechanism.	Complete mechanism and pole (with interrupters) replaced.

Incident Date	Station	kV	CB Manuf.	CB Designation	Technology	Duty	Age (years) at time of failure	Nature of Failure	Remedial Action
17/06/2015	MLTS	220	[C.I.C]	[C.I.C]	LT	Transf./Line/ Bus Tie	32	Hydraulic failed	Hydraulic Ram replaced
24/02/2017	SVTS	220	[C.I.C]	[C.I.C]	Minimum Oil	Transf./Line/ Bus Tie	48	Cracked rotating drive insulator	Replaced drive rid insulator
3/05/2017	TTSX	66	[C.I.C]	[C.I.C]	SF6 – Live tank	Cap Bank	27	CB Mech	Replaced the mechanism
31/05/2017	LYPS	500	[C.I.C]	[C.I.C]	CBLT	Transf./Line/ Bus Tie	31.6	Multiple hydraulic issues across the phases in short succession	Whole 3 phase CB replaced
6/06/2017	MLTS	220	[C.I.C]	[C.I.C]	SF6 – DT or GIS	Generator	1	Hydraulic failed	Hydraulic Ram replaced
17/06/2017	SVTS	66	[C.I.C]	[C.I.C]	CBLT	Cap Bank	26.6	Explosive failure of red phase interrupter expelling oil and causing CB fire.	CB Replaced
23/06/2017	SVTS	66	[C.I.C]	[C.I.C]	SF6 – Live tank	Cap Bank	27	Replace faulty CB	Replaced CB
9/07/2017	SVTS	66	[C.I.C]	[C.I.C]	CBLT	Cap Bank	38	CB Failure due to possible contact restrike and contact erosion	CB replaced
8/09/2017	KTS	500	[C.I.C]	[C.I.C]	CBLT	Transf./Line/ Bus Tie	15.7	Loose pre-insertion contact crown became jammed in interrupter	Complete CB Pole replacement
9/11/2017	KTS	500	[C.I.C]	[C.I.C]	CBLT	Transf./Line/ Bus Tie	7.3	Rupture disc operated.	CB head replaced
29/12/2017	EPSY	220	[C.I.C]	[C.I.C]	SF6 – Live tank	Generator	4	EPSY- replace 1 GEN TR 220KV CB Rph	CB replaced
2/03/2018	GTSX	220	[C.I.C]	[C.I.C]	SF6 – Live tank	Transf./Line/ Bus Tie	35	Hydraulic failed	Hydraulic Ram replaced

Incident Date	Station	kV	CB Manuf.	CB Designation	Technology	Duty	Age (years) at time of failure	Nature of Failure	Remedial Action
3/04/2018	BLTS	220	[C.I.C]	[C.I.C]	Minimum Oil	Transf./Line/ Bus Tie	43	Interrupter Head	Interrupter Head replaced
4/04/2018	ERTS	220	[C.I.C]	[C.I.C]	Minimum Oil	Transf./Line/ Bus Tie	42	Interrupter Head	Interrupter Head replaced
16/07/2018	HOTS	66	[C.I.C]	[C.I.C]	CBLT	Cap Bank	13	Internal flashover	CB replaced
3/08/2018	ROTS	220	[C.I.C]	[C.I.C]	SF6 – Live tank	Cap Bank	24	CB Pole	defective CB pole replaced
5/09/2018	WMTS	220	[C.I.C]	[C.I.C]	SF6 – Live tank	Transf./Line/ Bus Tie	33	Defective high resist heads S/C	defective CB pole replaced
18/10/2018	SVTS	66	[C.I.C]	[C.I.C]	Bulk Oil	Transf./Line/ Bus Tie	51	Replacement of the SVTS 1-2 B/T CB	CB replaced
26/10/2018	MLTS	220	[C.I.C]	[C.I.C]	SF6 – Live tank	Transf./Line/ Bus Tie	35	Hydraulic failed	Hydraulic Ram replaced
17/12/2018	GTS	220	[C.I.C]	[C.I.C]	SF6 – Live tank	Transf./Line/ Bus Tie	35	Hydraulic failed	Hydraulic Ram replaced
18/12/2018	GTS	220	[C.I.C]	[C.I.C]	SF6 – Live tank	Transf./Line/ Bus Tie	37	Hydraulic failed	Hydraulic Ram replaced
2/08/2019	LYPS	500	[C.I.C]	[C.I.C]	CBLT	Line	17	Guide for pre-insertion resistor broken,	CB pole replaced
14/10/2019	MLTS	220	[C.I.C]	[C.I.C]	SF6 – Live tank	Transf./Line/ Bus Tie	36	Hydraulic failed	Hydraulic Ram replaced
7/02/2020	WOTS	330	[C.I.C]	[C.I.C]	SF6 – Live tank	Transf./Line/ Bus Tie	34	Mechanism failed	Replaced the mechanism
22/04/2020	GTS	220	[C.I.C]	[C.I.C]	SF6 – Live tank	Transf./Line/ Bus Tie	37	Hydraulic failed	Hydraulic Ram replaced

Incident Date	Station	kV	CB Manuf.	CB Designation	Technology	Duty	Age (years) at time of failure	Nature of Failure	Remedial Action
30/04/2020	MLTS	220	[C.I.C]	[C.I.C]	SF6 – Live tank	Transf./Line/ Bus Tie	37	Hydraulic failed	Hydraulic Ram replaced
30/07/2021	ROTS	220	[C.I.C]	[C.I.C]	SF6 – Live tank	Cap Bank	31	Open circuit trip coil and burnt resistor	Mechanism replaced
1/9/2021	MLTS	220	[C.I.C]	[C.I.C]	SF6 – Live tank	Transf./Line/ Bus Tie	38	Hydraulic oil leak	Repaired
14/11/2021	LYPS	500	[C.I.C]	[C.I.C]	SF6 – Live tank	Transf./Line/ Bus Tie	38	The circuit breakers oil circuit failed.	Removed burst hydraulic line and refit line
4/1/2023	HWTS	500	[C.I.C]	[C.I.C]	SF6 – Live tank	Transf./Line/ Bus Tie	42	CB Hydraulic Pump sticking	Rebuild Hydraulic Pump
11/9/2023	MLTS	220	[C.I.C]	[C.I.C]	SF6 – Live tank	Transf./Line/ Bus Tie	38	Hydraulic Pump continuously running. CB failed to close	Repaired
8/11/2023	MBTS	220	[C.I.C]	[C.I.C]	CBDT	Transf./Line/ Bus Tie	16	Arching contacts in interrupting chamber	Replaced
27/11/2023	BLTS	66	[C.I.C]	[C.I.C]	Bulk Oil	Transf./Line/ Bus Tie	55	Failure of White Phase No.2 Bus Side Bushing	CB replaced
5/6/2024	MLTS	500	[C.I.C]	[C.I.C]	SF6 – Live tank	Transf./Line/ Bus Tie	42	Arcing contact faulty	Repaired
12/11/2024	YPS	220	[C.I.C]	[C.I.C]	CBMO	Transf./Line/ Bus Tie	47	Loose retaining screw on X coil, CB open too slow, bus tripped	All screws tightened, full operational checks carried out
4/01/2025	SMTS	500	[C.I.C]	[C.I.C]	CBGIN	Transf./Line/ Bus Tie	44	Hydraulic pump continuously cycling due to the CB not holding oil pressure.	Repaired – mechanism accumulators replaced
11/02/2025	SYTS	500	[C.I.C]	[C.I.C]	CBGIN	Transf./Line/ Bus Tie	41	hydraulic failure. The hydraulic started to leak	Mechanism replaced

Incident Date	Station	kV	CB Manuf.	CB Designation	Technology	Duty	Age (years) at time of failure	Nature of Failure	Remedial Action
								(high pressure) about 20m until a block alarm came up	
26/08/2025	EPS	220	[C.I.C]	[C.I.C]	SF6 – Live tank	Generator	12 (refurbished in 2013)	CB in indiscriminate state, mechanical fault (Very High operation Circuit breaker)	Mechanism Replaced

Appendix 2 - Program of Works

FLOC DESCRIPTION	OBJECT TYPE	START-UP DATE	VOLTAGE	MANUFACTURER	MODEL	STATION
2-3 22KV B/T CB	CBBO	3/21/1965	22	[C.I.C]	[C.I.C]	BLTS
2 GEN TR 220KV CB	CBLT	12/12/2004	220	[C.I.C]	[C.I.C]	EPSY
1 GEN TR 220KV CB	CBLT	6/1/2013	220	[C.I.C]	[C.I.C]	EPSY
4 220KV CAP BK CB	CBLT	12/7/1997	220	[C.I.C]	[C.I.C]	FBTS
1-2 66KV B/T CB	CBBO	6/30/1968	66	[C.I.C]	[C.I.C]	FTS
CBTS 1 66KV L CB	CBBO	6/30/1968	66	[C.I.C]	[C.I.C]	FTS
CBTS 2 66KV L CB	CBBO	6/30/1968	66	[C.I.C]	[C.I.C]	FTS
FSH 66KV FDR/FTS BY-PASS CB	CBBO	6/30/1968	66	[C.I.C]	[C.I.C]	FTS
FTN 66KV FDR CB	CBBO	5/20/1970	66	[C.I.C]	[C.I.C]	FTS
LWN 66KV FDR CB	CBBO	4/20/1969	66	[C.I.C]	[C.I.C]	FTS
TBTS 66KV L/FTS BY-PASS CB	CBBO	3/27/1969	66	[C.I.C]	[C.I.C]	FTS
WN 2 66KV FDR CB	CBBO	3/16/1970	66	[C.I.C]	[C.I.C]	GNTS
BN 1 66KV FDR CB	CBBO	6/30/1970	66	[C.I.C]	[C.I.C]	GNTS
BN 2 66KV FDR CB	CBBO	6/30/1970	66	[C.I.C]	[C.I.C]	GNTS
CHM/IKA 66KV FDR CB	CBBO	4/16/1970	66	[C.I.C]	[C.I.C]	HOTS
HSM 1 66KV FDR CB	CBBO	4/16/1970	66	[C.I.C]	[C.I.C]	HOTS
HSM 2 66KV FDR CB	CBBO	11/25/1969	66	[C.I.C]	[C.I.C]	HOTS
KWF 66KV FDR CB	CBBO	3/31/1980	66	[C.I.C]	[C.I.C]	HOTS
STL 2 66KV FDR CB	CBBO	6/30/1966	66	[C.I.C]	[C.I.C]	HOTS
1B 66KV CAP BK CB	CBLT	6/30/2000	66	[C.I.C]	[C.I.C]	HTS
HWPS 2 220KV L CB	CBMO	6/30/1980	220	[C.I.C]	[C.I.C]	JLTS
HWPS 1 220KV L CB	CBMO	6/30/1980	220	[C.I.C]	[C.I.C]	JLTS
2 66KV CAP BK CB	CBLT	9/30/2005	66	[C.I.C]	[C.I.C]	KGTS
LYS 3 66KV FDR 2 BUS CB	CBMO	6/30/1982	66	[C.I.C]	[C.I.C]	LYXX
LYS 3 66KV FDR 1 BUS CB	CBMO	6/30/1982	66	[C.I.C]	[C.I.C]	LYXX
1 SVC 1 BUS CB	CBMO	12/12/1982	220	[C.I.C]	[C.I.C]	ROTS
A1 TR/2 SVC 220KV CB	CBMO	5/11/1983	220	[C.I.C]	[C.I.C]	ROTS
SVTS 2 220KV L/1 SVC CB	CBMO	12/12/1982	220	[C.I.C]	[C.I.C]	ROTS
2 SVC 3 BUS CB	CBMO	12/22/1982	220	[C.I.C]	[C.I.C]	ROTS
2 220KV CAP BK CB	CBLT	6/1/1990	220	[C.I.C]	[C.I.C]	ROTS
1 66KV CAP BK CB	CBLT	8/24/2018	66	[C.I.C]	[C.I.C]	TGTS
ROTS 5 220KV L 2 BUS CB	CBMO	6/30/1977	220	[C.I.C]	[C.I.C]	YPSX
ROTS 6 220KV L 1 BUS CB	CBMO	6/30/1977	220	[C.I.C]	[C.I.C]	YPSX
HWPS 1 220KV L CB	CBMO	6/30/1977	220	[C.I.C]	[C.I.C]	YPSX
HWPS 2 220KV L 2 BUS CB	CBMO	6/30/1977	220	[C.I.C]	[C.I.C]	YPSX

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