AMS – Victorian Electricity Transmission Network

Circuit Breakers (PUBLIC VERSION)

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Disclaimer

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Table of Contents

1 Executive Summary

This document defines the asset management strategies for AusNet Services' population of 1,096 circuit breakers in the Victorian electricity transmission network to maintain the safety, reliability, quality and security of supply of service.

A summary of the circuit breaker population by voltage class and insulating medium is provided in Table 1 below.

	Voltage								
Type	**500 kV**	**330 kV**	**220 kV**	**275 kV**	**66 kV**	**22 kV**	**6.6 kV**	**4.5 kV**	**Total**
SF_6 - Live Tank	61	22	86	4	113	9	0	2	**297**
SF_6 - Dead Tank	0	0	219	0	167	2	0	0	**388**
Bulk Oil	0	0	28	0	159	45	13	0	**245**
Minimum Oil	0	3	49	0	69	2	0	0	**123**
Vacuum	0	0	0	0	0	34	0	0	**34**
Air Blast	0	0	7	0	0	0	0	0	**7**
Air Break	0	0	0	0	0	0	2	0	**2**
Total	**61**	**25**	**389**	**4**	**508**	**92**	**15**	**2**	**1096**

Table 1 – Circuit Breakers by Voltage Class and Insulating Medium (as at Jul 2014)

The overall strategic approach involves addressing those circuit breakers with high failure risks by virtue of their poor condition, modes of failure or location in critical circuits through specialised maintenance or refurbishment and selective replacement programs. Approximately 34% of circuit breakers in the fleet are in C4 condition while another 7% are in C5 condition.

The circuit breaker risk assessment using the Availability Workbench software demonstrated a significant overall cost saving through planned replacement of 344 circuit breakers in C4 and C5 condition over the next ten-year period. This is the most efficient use of limited resources and a prudent investment for customers.

Planned station rebuild projects integrating the network augmentation needs of the Australian Energy Market Operator (AEMO) and distribution network service providers (DNSP) with asset replacement needs will include the economic replacement of 53 circuit breakers over the period 2015 to 2022.

Key strategies for the circuit breakers include:

- Replace [C.I.C] bulk oil circuit breakers by 2022.
- Replace high risk 220 kV minimum oil [C.I.C] circuit breakers by 2022.
- Prioritise replacement of 220kV minimum oil CBs in poor condition; [C.I.C] and [C.I.C] types by 2022.
- Replace 66 kV [C.I.C] circuit breakers by 2022.
- Prioritise replacement of [C.I.C] CBs in poor condition within next seven years.
- Refurbish [C.I.C] circuit breakers within next seven years.
- Continue to repair SF_6 leaks in a timely manner.
- Review the performance of older SF_6 CBs and develop refurbishment programs as required.
- Replace poor performing SF_6 Capacitor Bank CBs such as [C.I.C] type before second wear out refurbishment.
- Monitor developments of vacuum technology at 66kV and introduce SF_6 free CBs into the network, where economic.

2 Introduction

2.1 Purpose

The purpose of this document is to define the asset management strategies for the Victorian electricity transmission network's population of circuit breakers. This strategy is intended to assist personnel involved in managing the assets, meeting regulatory obligations and informing other stakeholders by:

- presenting an overview of the circuit breaker population;
- prudently managing the emerging performance risks presented by circuit breakers;
- achieving network availability and reliability targets taking account of risk, costs and customer expectations; and
- effective and economic management of circuit breakers throughout their life-cycle.

2.2 Scope

This asset management strategy applies to AusNet Services' circuit breakers associated with the Victorian electricity transmission network. The document does not include management of circuit breakers associated with gas insulated switchgear (GIS) installations, which are documented in document AMS 10-62 Gas Insulated Switchgear[1].

The strategies in this document are limited to maintaining installed capability in terms of equipment performance and rating. Improvements in quality or capacity of supply are not included in the scope of this document.

[1] Condition assessment of 22 kV switchboard CBs are included in AHR 10-62.

3 Asset Summary

Circuit breakers are electrical switches that, in conjunction with protection systems, operate automatically to protect the public and workers from electrical hazards and protect the electricity network from damage caused by overload and short-circuit faults. Circuit breakers are also used in day to day network operations to switch capacitor banks and to isolate parts of the network to enable maintenance or augmentation works.

Some of the common types of circuit breakers available in the network are; Bulk oil, Minimum oil, SF_6 and Vacuum. Figure 1 below illustrates a bulk oil 66 kV circuit breaker typical of a technology which is now nearing the end of its useful service life. Figure 2 below illustrates a modern 220 kV SF_6 gas insulated dead tank circuit breaker featuring toroidal CTs in the base of each bushing. Circuit breakers of this type are expected to provide more than 40 years reliable service.

Figure 1 – 66 kV Bulk oil CB

Figure 2 – 220 kV SF_6 CB

3.1 Population

AusNet Services has a total of 1096 circuit breakers installed in the transmission network as at July 2014. A summary of the circuit breaker population by voltage class and insulating medium is provided in Table 2.

	Voltage								
Type	**500 kV**	**330 kV**	**220 kV**	**275 kV**	**66 kV**	**22 kV**	**6.6 kV**	**4.5 kV**	**Total**
SF_6 - Live Tank	61	22	86	4	113	9	0	2	**297**
SF_6 - Dead Tank	0	0	219	0	167	2	0	0	**388**
Bulk Oil	0	0	28	0	159	45	13	0	**245**
Minimum Oil	0	3	49	0	69	2	0	0	**123**
Vacuum	0	0	0	0	0	34	0	0	**34**
Air Blast	0	0	7	0	0	0	0	0	**7**
Air Break	0	0	0	0	0	0	2	0	**2**
Total	**61**	**25**	**389**	**4**	**508**	**92**	**15**	**2**	**1096**

Table 2 – Circuit Breakers by Voltage Class and Insulating Medium (as at July 2014)

The seven remaining 220 kV Air Blast circuit breakers (CBs) at Glenrowan Terminal Station (GNTS) were replaced by SF_6 dead tank CBs late in 2014. These were the last sets of Air Blast circuit breakers in the Victorian electricity transmission network.

In the last five years, a total of 144 of the following types of circuit breakers have been replaced or decommissioned:

- Bulk oil – 78 units;
- Air-blast – 44 units;
- Minimum oil – 18 units;
- Vacuum – 3 units; and
- SF_6 – 1 unit.

Circuit breakers operating at voltages above 66 kV have been replaced with SF_6 units and 22 kV circuit breakers have primarily been replaced with Vacuum technology units.

The population of circuit breakers includes units constructed by 17 manufacturers and comprises 66 different types. Majority of circuit breakers were manufactured by [C.I.C]. The large variety of circuit breaker types presents complexities in developing safe working methods, retaining maintenance knowledge and skills, undertaking condition assessments, completing contingency planning and managing spares inventory due to specific differences in physical design and construction characteristics between each type.

Figure 3 and Figure 4 present the circuit breaker population by voltage and type respectively.

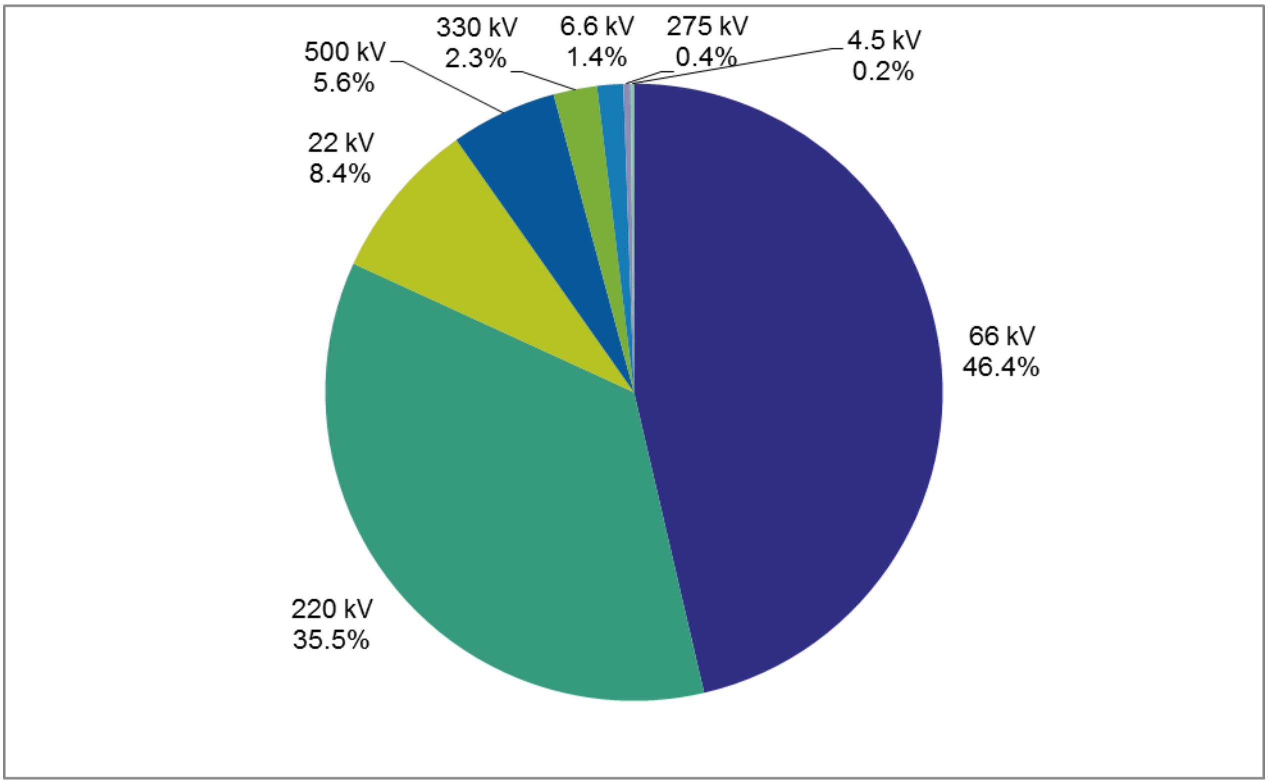

Figure 3 – Circuit Breakers by Voltage (as at July 2014)

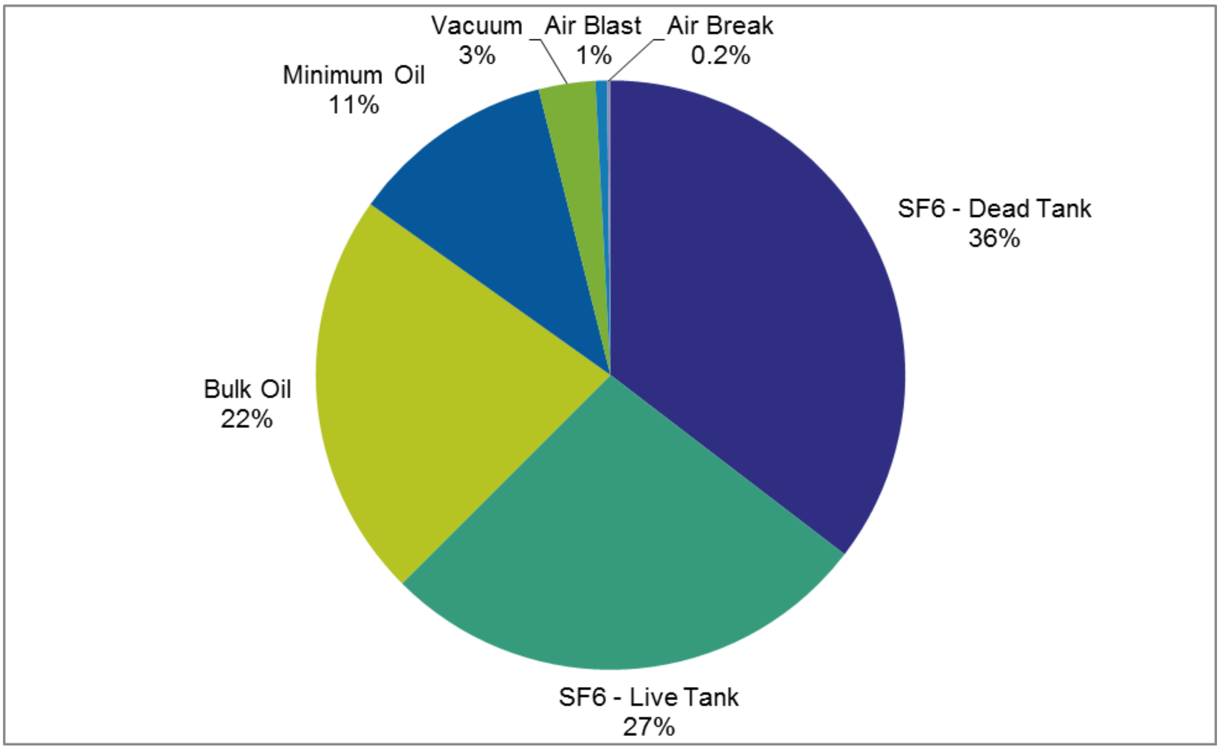

Figure 4 – Circuit Breaker Population by Type (as at July 2014)

A summary list of circuit breaker manufacturers and types is provided in Appendix A.

3.2 Service Age

Transmission circuit breakers have a nominal expected service life of 45 years[2]. AusNet Services currently has 204 units installed that exceed this nominal expected service life, with a further 63 units approaching this nominal expected service life. The average service age[3] of the transmission circuit breaker population is 21 years. Table 3 shows the average age of the circuit breaker population by type.

If no circuit breakers were to be replaced during next five years the number of circuit breakers exceeding their nominal expected service life would increase to 267 which is approximately a quarter of the total population of circuit breakers.

[2] Source: New York Transmission Oil Circuit Breaker Replacement Strategy – Nov 2010.

[3] Note that AusNet Services' asset age data is based on the asset installation date, not the manufactured date.

Type	Average Service Age (Years)	Volume
Air-blast[4]	48	7
Bulk oil	47	245
Minimum oil	35	123
SF_6 – Dead Tank	6	388
SF_6 – Live Tank	16	297
Vacuum	8	34
Air-break[5]	47	2
All units	**21**	**1096**

Table 3 – Average Age of Transmission Circuit Breakers (as at July 2014)

AusNet Services participates in the International Transmission Operations and Maintenance Study (ITOMS). This formal benchmarking exercise enables AusNet Services to compare asset age with other transmission companies. The 2013 ITOMS[6] results confirm that AusNet Services' fleet of transmission circuit breakers is relatively old, ranking seventh oldest in the survey group of 32 transmission companies.

Figure 5 and Figure 6 present the age profile of AusNet Services' circuit breaker population based on service voltage and type respectively.

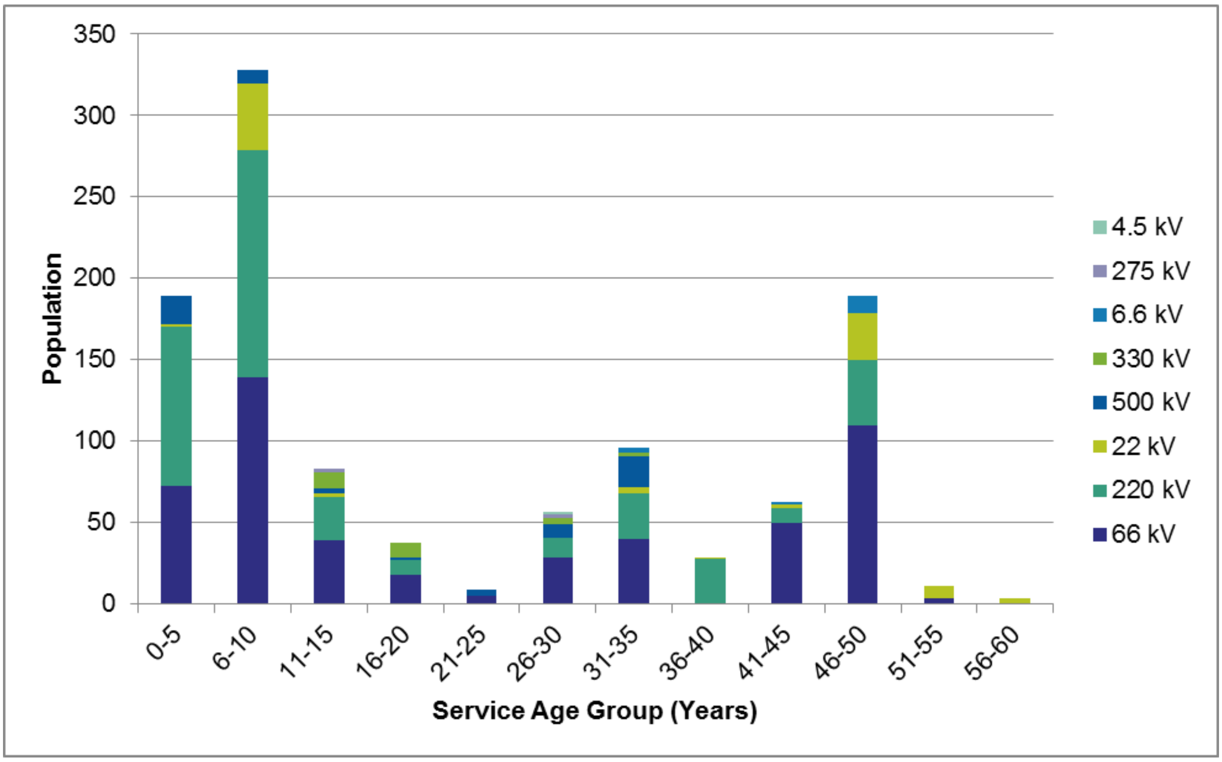

Figure 5 – Circuit Breakers Service Age by Voltage (as at July 2014)

[4] All the remaining Air-blast circuit breakers were replaced at the end of 2014.

[5] Two Air-break circuit breakers are 6.6 kV [C.I.C] type Synchronous Condenser start motor CBs at TSTS and FBTS.

[6] Transmission Breaker Maintenance – ITOMS (International Transmission Operations and Maintenance Study) 2013 Report.

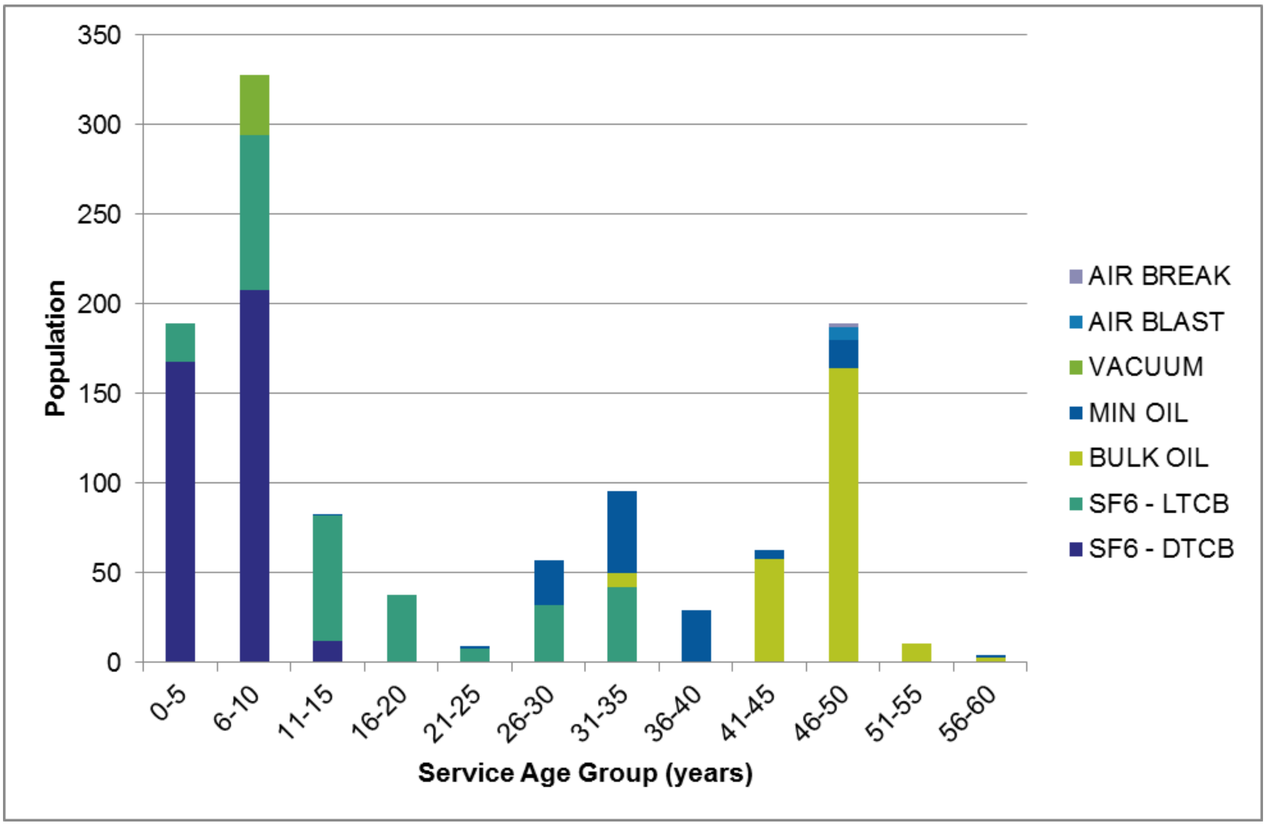

Figure 6 – Circuit Breakers Service Age by Type (as at July 2014)

More than 96% of the bulk-oil circuit breakers operating at 220 kV, 66 kV and 22 kV are currently older than 40 years and 73% of the bulk-oil circuit breakers have exceeded 45 years of service life. All the SF_6 Dead tank circuit breakers are less than 15 years old while Vacuum circuit breakers are less than 10 years old. The most economic circuit breaker technologies used for new installations and replacements are:

- SF_6 live tank – 275 kV and above and capacitor banks.
- SF_6 dead tank – 66 kV and 220 kV and AIS 22 kV.
- Vacuum – non-GIS metal clad switchboards[7].

3.3 Condition

The population of circuit breakers has been assessed using a framework that includes a condition rating for each circuit breaker in the Victorian transmission network. The statistical data on individual circuit breaker maintenance is used to develop an individual predictive assessment of the asset condition taking failure mode criticality, technical obsolescence, switching duty, asset maintainability, failures during warranty and major refurbishments on the CB in to account. For further details on the circuit breaker condition assessment refer to AHR 10-54 “Victorian Electricity Transmission Network Asset Health report - Circuit Breakers”.

Table 4 provides the condition scoring matrix used to evaluate the condition of the circuit breakers in the Victorian transmission system.

[7] SF_6 switchboards switch boards with an insulating pressure less than 300kPA and vacuum interruption are considered metal clad switchgear rather than GIS.

Condition Score	Condition Description	Summary of Details of Condition Score	Remaining Service Potential
C1	Very Good	These CBs are generally less than 15 years old and in good operating condition with no past history of significant defects or failures. Manufacturer support and spares are readily available for routine maintenance.	95%
C2	Good	This category includes CBs which are in better than average condition for its service age and technology type. They may have some minor issues such as minor oil or SF_6 leaks from seals, minor corrosion, and minimal 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. Manufacturer support and spares are available.	70%
C3	Average	This category includes CBs which are in average condition for its respective service age and technology type. They may have developed several issues due to in service related deterioration, such as interrupter wear, oil/ SF_6 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. These CBs are showing signs of deterioration in condition or performance.	45%
C4	Poor	This category includes CBs which are in worse than average condition. They have developed an increasing number of issues such as interrupter wear out, worsening oil or SF_6 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 SF_6 leaks, component breakages and typically worn out or unreliable operating mechanisms and significant failures. These CBs are approaching the end of their 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 4 – Condition Scoring Framework for Circuit Breakers

AusNet Services has 74 circuit breakers that are in "very poor" condition. They are assessed as having little remaining service life and require refurbishment or replacement in the short-term. These circuit breakers have one or more major components in "very poor condition" and have generated a significant number of corrective maintenance (CM) work orders in recent years.

A further 369 units are assessed as in "poor" condition and require refurbishment or replacement in a two to 10 year time frame. More than 40% of circuit breaker population is currently in "very poor" or "poor" condition.

The types of units that are rated as being in very poor condition (C5) include the following:

- 500 kV [C.I.C] – 12 units (SF_6);
- 220 kV [C.I.C] – 9 units (minimum oil);
- 220 kV [C.I.C] – 7 units (bulk oil);
- 22 kV [C.I.C] – 6 units (bulk oil);
- 500 kV [C.I.C] – 5 units (SF_6);
- 220 kV [C.I.C] – 5 units (SF_6);
- 66 kV [C.I.C] – 5 units (minimum oil);
- 66 kV [C.I.C] - 4 units (bulk oil);
- 66 kV [C.I.C] – 4 units (minimum oil); and
- 66 kV [C.I.C] – 4 units (SF_6).

Most of the units rated in "very poor" condition also have advanced service ages. However some units, such as some of the 66 KV [C.I.C] type CBs are in "very poor" condition due to the high operation duty resulting from switching capacitor banks.

Figure 7 provides a summary of the condition of the circuit breaker fleet based on type.

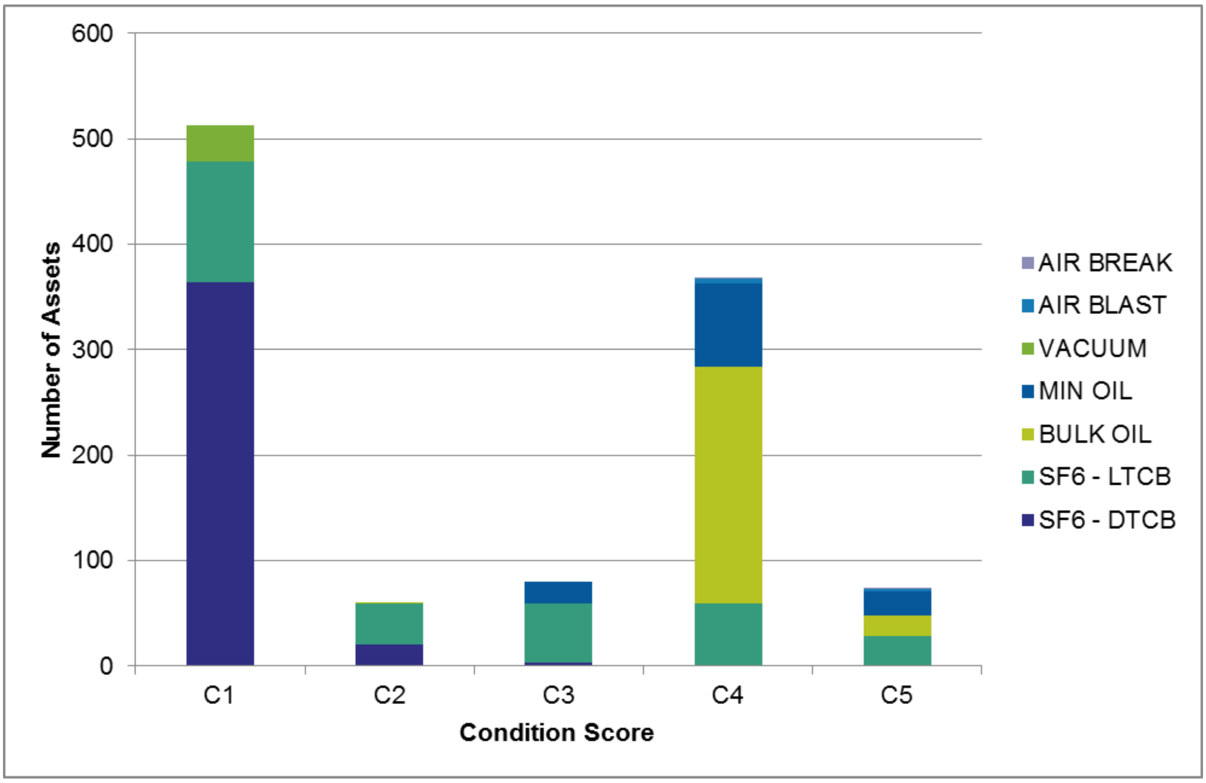

Figure 7 – Circuit Breakers Condition Assessment by Type (as at July 2014)

Figure 8 illustrates a comparison between 2015 and 2012 circuit breaker condition profiles. It is evident that circuit breaker replacements during past three years were sufficient to maintain the circuit breaker condition profile.

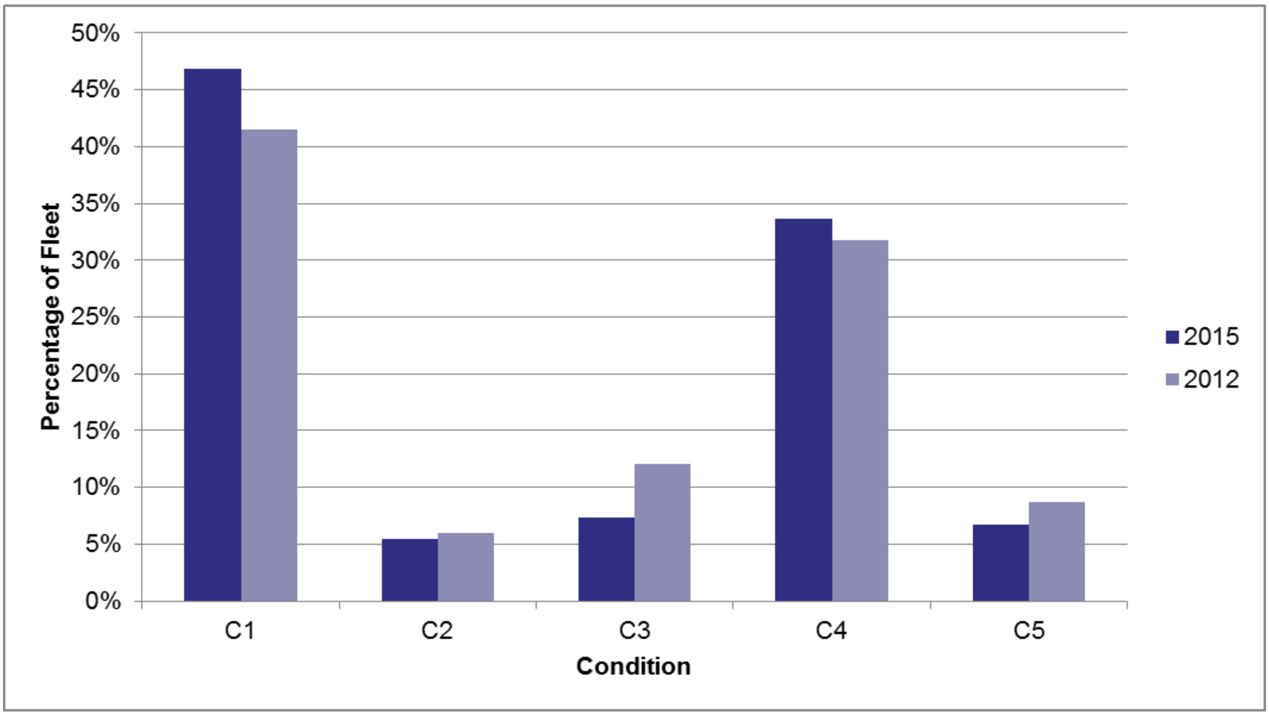

Figure 8 – Circuit Breaker Condition Comparison 2012 and 2015

3.4 Performance

This section provides an overview of performance issues associated with the circuit breaker population.

3.4.1 Significant Defects and Failures

AusNet Services has experienced 54 significant defects and failures associated with its circuit breaker population since 1997. This represents a long-term average of approximately 0.3 significant failures per 100 circuit breaker (CB) years.

A significant failure is defined as a failure that causes a complete functional failure and requires complete asset replacement or replacement of a major subsystem before the asset can be restored to service. Significant failures will have consequences on safety, network availability or adjacent assets. An in-depth investigation will follow to mitigate potentially significant fleet implications for safety or reliability.

Figure 9 depicts the significant defects and failures experienced from 1997 to 2014 by CB technology.

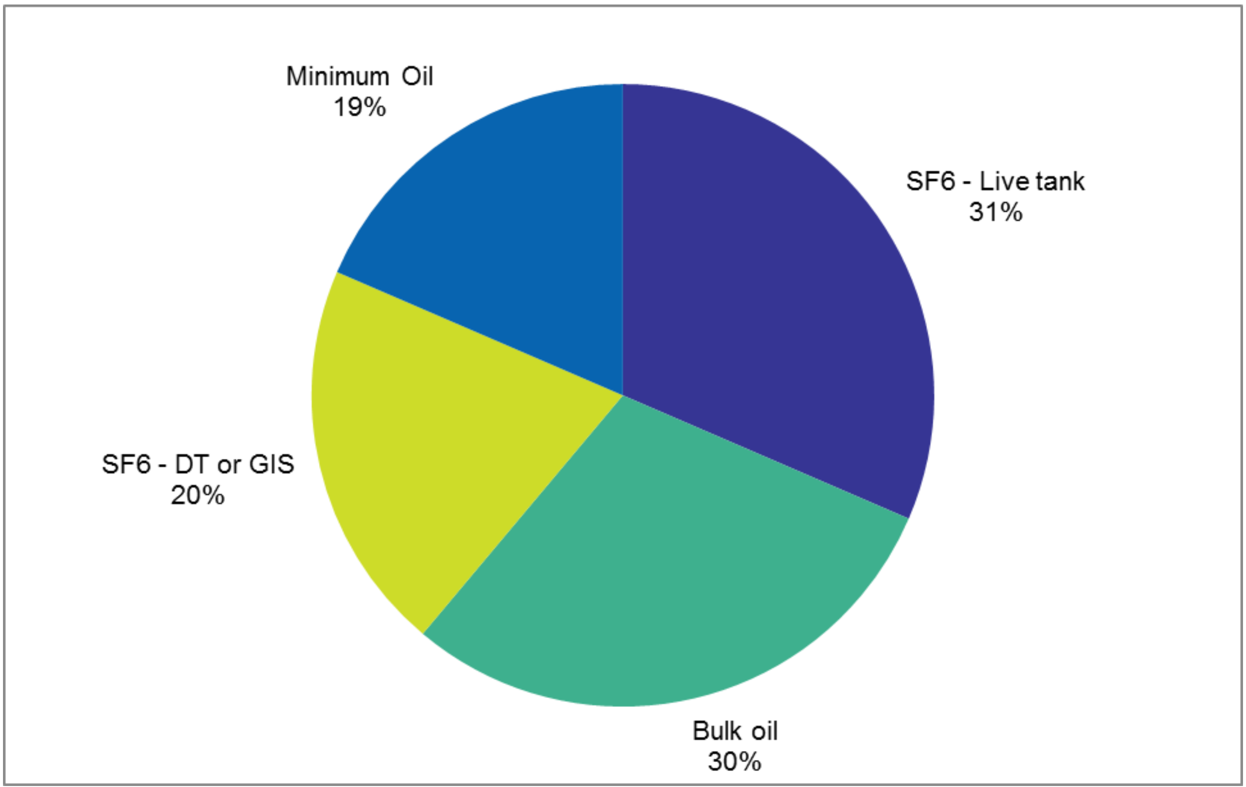

Figure 9 – Significant Defect and Failure History by Technology: 1997 to 2014

Table 5 lists the most frequent significant defects and failures from the 54 major failures recorded since 1997. The greatest number of significant failures was observed in the [C.I.C] bulk oil circuit breaker fleet. Almost all of these major failures are associated with bushing insulation failures. Two of the major failures were explosive in nature presenting risks to workers and nearby equipment (for further details refer to Appendix B).

Manufacturer & Type	Voltage	Number of Major Defects / Failures	Comments
[C.I.C][8]	220	7	Six of the failures are associated with Bushings.
[C.I.C]	220	6	Five of the failures are associated with Bushings.
[C.I.C]	66	6	Four of the failures are during operation.
[C.I.C]	66	3	During operation.
[C.I.C]	220	3	Two of the failures are during operation.
[C.I.C]	500	3	During operation.
[C.I.C]	220	3	Partial close operation.
[C.I.C]	66	3	One of the failures is associated with bushings, one associate with mechanism and the other during operation.

Table 5 – Major Failure History by Manufacturer and Type: 1997 to 2014

[8] [C.I.C] CBS have been replaced since preparing this document.

Figure 10 shows the major circuit breaker defects and failures by duty.

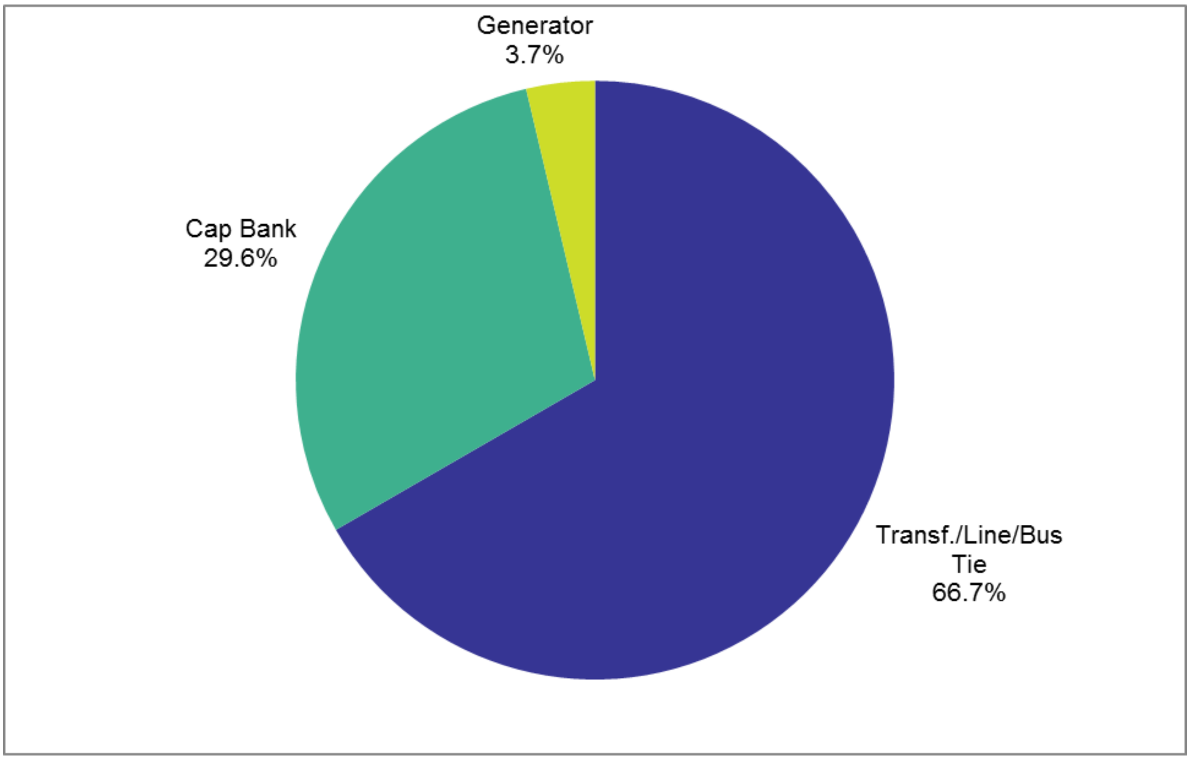

Figure 10 – Significant Defect and Failure by Duty

3.4.2 Work Order Analysis

AusNet Services routinely analyses the root causes of unplanned work undertaken on circuit breakers. Records for unplanned work undertaken on the circuit breaker population are maintained in the Asset Management System, Maximo (In SAP based Enterprise Asset Management information system from May 2015).

Figure 11 depicts the overall number of unplanned corrective maintenance (CM) work orders issued per annum for circuit breakers in the period between January 2005 and December 2014 (including major defects and failures). The majority of work orders are for SF_6 live tank circuit breakers. Most of these work orders are due to issues relating to circuit breaker housing / enclosures causing SF_6 gas leaks. Bulk oil circuit breakers have the second highest number of CM work orders.

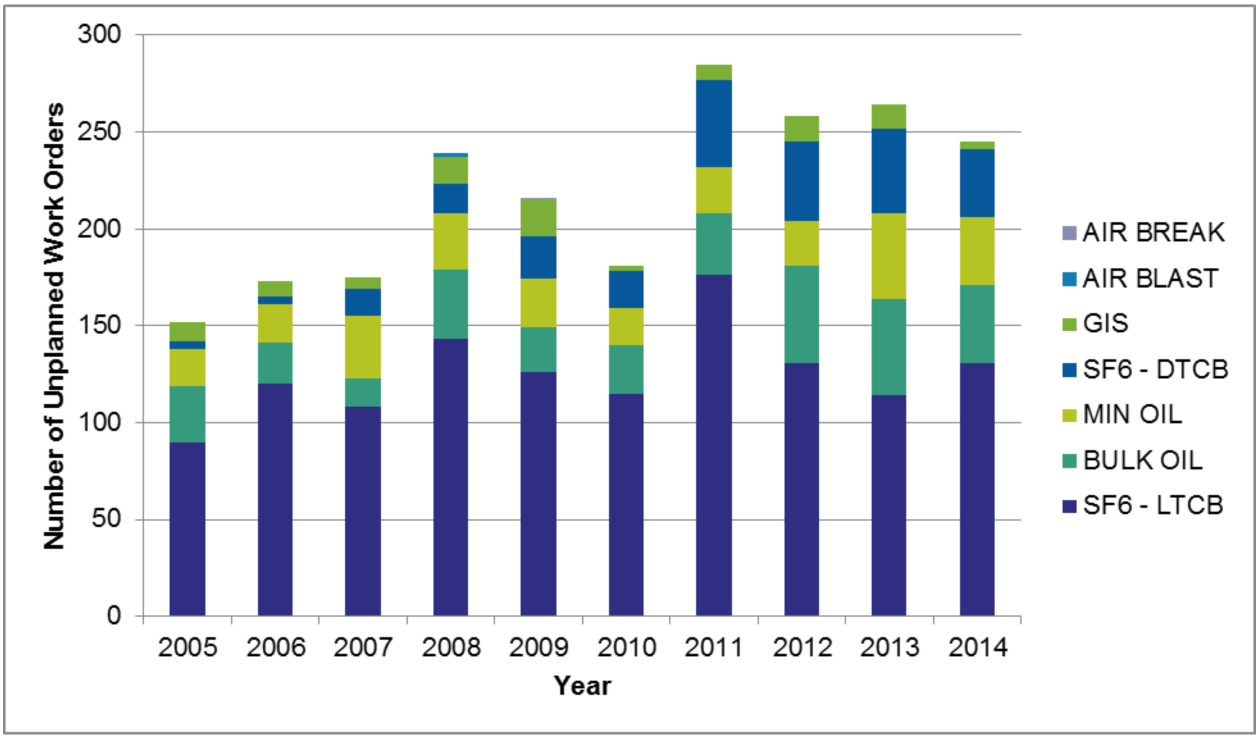

Figure 11 – Work Order History by Circuit Breaker Type: 2005 to 2014

Figure 11 shows that despite an increase in the overall volume of circuit breakers in service the total number of work orders declined between 2008 and 2010 with a reduction in the number of defects associated with air-blast, bulk oil and minimum oil types of circuit breakers, which is largely a result of the replacement programs and decreasing populations of those types of units.

However, the number of work orders issued in 2011 increased as work orders for SF_6 gas insulated units exceeded the annual total for all previous years. This increasing trend is a result of the increasing level of unplanned work associated with rectifying SF_6 leaks. Number of work orders for bulk oil circuit breakers shows an increasing trend since 2011, mainly due to the aging population that is nearing the end of its useful life. In the recent years minimum oil circuit breakers also caused an increased number of unplanned work orders due to deteriorating condition.

Error! Reference source not found. shows the circuit breaker types with the highest number of CM work orders per circuit breaker during the period between January 2005 and December 2014. Each of the types that exhibit high work order volumes are either in “very poor” or “poor” condition and has been the target of specific corrective maintenance/refurbishment or replacement to reduce the level of unplanned maintenance required.

[C.I.C]

Figure 12 depicts the percentage of CM work orders categorised according to circuit breaker components. The main issue evident is the increasing number of SF_6 gas leaks presented by the circuit breaker population captured in housing/enclosure. This is partly contributed by more than 62% of SF_6 type circuit breaker population. In addition, there has been a recent increase in work orders associated with circuit breaker mechanisms.

Auxiliary systems include cubicle heaters, cyclometers, Amp meters, oil gauges, breathers and SF_6 gas density monitors required for the correct functionality of circuit breakers.

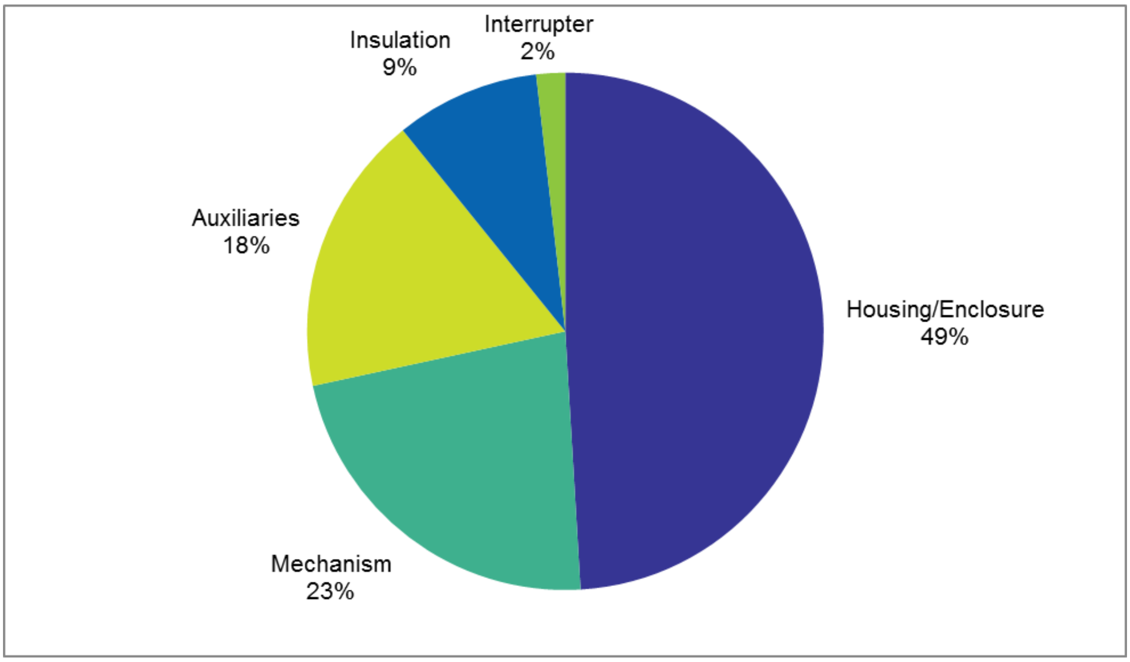

Figure 12 – Annual Work Order History by Circuit Breaker Component

3.4.3 Impact of failures

Circuit breaker failures have had the general impacts shown in Table 6.

Failure	Classification	Impact
Does not open on command	Network	Damage to network due to excess fault current.
	Customer	Damage to generator or customer plant due to excess fault current.
	Safety	Public or personnel exposed to faulted network.
Does not close on command	Network	Network not available; generation market constraints, reduced security or extended outages.
	Customer	No supply or no capacity to generate.
Fails to stay closed (spurious operation)	Network	Network not available; constraints, reduced security or extended outages.
	Customer	No supply or no capacity to generate.
Explosion	Network	Damage to CB and damage to adjacent plant.
	Safety	Injury (including possible fatal injury) to personnel or public.
	Environmental	Oil contaminates land or waterway; greenhouse gas emission.
Oil or gas leak	Environmental	Oil contaminates land or waterway; greenhouse gas emission.
Flashover	Network	Network not available; generation market constraints, reduced security or extended outages.
	Safety	Injury to personnel.

Table 6 – Impact of Circuit Breaker failure

4 Strategic Factors

4.1 Safety

The majority of safety issues presented by the circuit breaker population relate to the fleet of [C.I.C] bulk oil circuit breakers. This type of circuit breaker presents the following issues:

- past history of explosive bushing failure, which presents significant risk to personnel working in the vicinity;
- routine preventive maintenance requires work in a confined space hazard;
- safety risks inside CB include oil fumes and high slipping hazard when working in or exiting tank;
- confined space rescue method inadequate – requires bushing removal or cutting access points in tanks;
- maintenance work is physically onerous (ie. manual handling of large, heavy components); and
- extensive oil handling required for contact inspections.

4.2 Environment

The main environmental issues associated with circuit breakers relate to the insulating medium used within the units and include the following risks:

- management of insulating oil; and
- management of SF_6 gas associated with gas-filled units.

4.2.1 Oil management

Oil insulated circuit breakers are susceptible to the issues of oil fires, ground absorption and escape into surrounding waterways. The largest oil filled CB contains 34,000 litres of oil (including oil in bushings), but most contain between 150 and 3,000 litres.

When the issue of PCB contamination first arose more than 15 years ago, tests for PCB contamination of the larger circuit breakers were performed and no PCBs were detected at a 'scheduled' level[9].

4.2.2 SF_6 management

Modern high-voltage and extra high-voltage circuit breakers use Sulphur Hexafluoride (SF_6) as the insulating medium. For a number of reasons SF_6 is superior to the insulation used in older circuit breakers. However, it is considered a greenhouse gas largely because it has a very long life in the atmosphere (about 3,000 years), while carbon dioxide and methane are broken down relatively quickly. For this reason it is considered to be 23,900 times more critical than the equivalent mass of carbon dioxide. While SF_6 leaks in switchgear are not significant contributors to the total quantity of greenhouse gases in the atmosphere, leakages do occur and they must be attended before the circuit breaker can be returned to service.

As shown by the Work Order analysis in section 3.4.2, leaks from ageing seals and corroding equipment are a continuing issue for older SF_6 CBs. Asset works programs have been developed to address these fleet issues.

[9] Any material (including material in equipment) which contains PCB's at level at or in excess of the threshold concentration (50mg/kg) and threshold quantity (50g).

4.3 Maintenance

This section provides an overview of maintenance issues associated with the circuit breaker population.

Extensive maintenance and refurbishment of circuit breakers is preferred to replacement in cases where it is a viable technical and economic option. For example, a recent refurbishment project involved the replacement of interrupter chamber in [C.I.C] type circuit breakers. This refurbishment involved removal of the circuit breaker from service and refurbishment in a workshop before reinstallation of the unit. Refurbishment is not viable where it will not substantially mitigate the risk or where the circuit breakers are technically obsolete and manufacturer support and spare parts are not available.

There is a shortage of experienced maintenance staff within the industry who are capable of maintaining or refurbishing old plant items. Inexperienced staff cause an increase in maintenance costs because of the training requirements. They can also reduce the quality of the maintenance or refurbishment work. There is a reluctance on the part of the original manufacturers to provide specialist advice or components except at a cost comparable to, or higher than, the cost of re-engineering the plant. Refer also to AMS 10–19 Plant and Equipment Maintenance strategy document.

With the overall reduction in personnel in the industry there are benefits to be gained through the remote reviewing of operational data (data that can be gained from monitors supplied integral with new CBs). The retrofitting of such condition monitors to existing CBs is expensive and the savings in field maintenance associated with remote monitoring are insufficient to make this factor a major driver although it has long-term benefits. The benefits of online monitors are in having the ability to ‘tailor’ maintenance intervals by bringing the maintenance forward to reduce the risk of failure or deferring maintenance on ‘good’ assets to reduce operations expenditure.

Maintenance savings for new SF_6 CBs can partly offset earlier installation although it is unlikely that maintenance savings alone can justify circuit breaker replacement.

4.4 Technology

This section provides an overview of technology issues and opportunities associated with the circuit breaker population. Due to the age span of the network many technologies and designs have been used, covering oil, air, vacuum and SF_6 interrupting medium and spring, hydraulic and pneumatic drive mechanisms. The older equipment, such as air blast and oil are now obsolete technologies presenting challenges of lack of spares, lack of manufacturer support and dwindling skilled resource. These circuit breakers have not been designed with current safety in design standards nor has their true capability been type tested to modern standards, which they are considered unlikely to pass. As such, care has to be taken when changing network configurations or re-use of these technologies.

In general terms the failure modes of older technology CBs, such as bulk oil CBs, tend to be less benign than modern equipment. Explosive failure modes including oil fires with collateral damage and environmental and safety risks tend to make failures of older technology CBs much more critical. Recovery from major failures also result in more expensive replacements and longer recovery times as typically a more modern CB has to be fitted in as the replacement.

Modern CB utilise dead tank technology and polymer insulation which ensures simpler, smaller footprints and inherently safer failure modes and safety design features, such as guarding. New technologies also allow online condition monitoring and diagnostic checks so more information can be determined about the true condition. New technologies being simpler also involve less routine maintenance, but also reduce skill and knowledge level with the equipment. Due to this simplicity and newer methods of construction, for example such as crimped connections rather than bolted, increasingly if a failure does occur with modern equipment, repairs are more expensive as major part or wholesale replacement of parts is required compare to the older technologies, where more component dismantling and re-assembly has been factored in.

4.5 Other Considerations

This section provides an overview of other issues associated with the circuit breaker population.

4.5.1 Rating

There is a clear case for CB replacement if the normal current rating is exceeded or the peak fault-current-withstand or interruption capability is exceeded. For the reasons mentioned in the previous section, upgrading the rating of CBs by replacing parts is rarely economic. The cost of ad hoc testing to confirm the new rating to an appropriate technical standard is an additional economic disincentive.

4.5.2 Operation Duty

Circuit breakers that are required to perform a large number of operations (for example, those used in capacitor bank switching) develop severe contact erosion and need frequent maintenance and overhaul in a workshop to replace worn out parts. The lifetime of these circuit breakers is very low compared to the circuit breakers that are used for normal operations. The onerous switching duty and significantly increased operating duty means that the service age of capacitor bank and reactor CBs is not a meaningful indicator of condition – the count of operations is a much better indication of condition.

Modern SF_6 CBs are sent to the original equipment manufacturer to be overhauled and have parts replaced.

4.5.3 Co-ordination of CT & CB replacement projects

Dead tank SF_6 circuit breakers are the preferred type for 220 kV and 66 kV new and replacement installations. These circuit breakers incorporate the current transformers and therefore the replacement of an existing circuit breaker with one of this type can also involve decommissioning and removal of current transformers. Projects are coordinated to ensure that current transformers are only considered for replacement where new dead tank SF_6 circuit breakers are not likely to be installed in the medium term.

5 Key Issues

The following sections provide a summary of the key issues associated with the circuit breaker fleet. Further information is provided in Circuit Breaker Asset Health Report (AHR 10-54).

5.1 Bulk Oil Circuit Breakers

The key issues associated with bulk oil circuit breakers include the following:

- increasing difficulty in ensuring safe working methods to modern safety standards
- poor mechanical condition, including age-related deterioration of mechanisms and drive systems
- deteriorated condition of bushings, which has led to hot-spots within bushings and subsequent explosive failure (mainly [C.I.C] units)
- maintenance intensive when compared with modern equivalent circuit breakers
- difficulties in assessing the condition of internal components, such as grading capacitors
- lack of available spares and manufacturers support
- fault-level limitations of some units that are installed in higher fault level service conditions
- 220 kV CBs require intensive maintenance of HP air systems and compressors.

5.2 Minimum Oil Circuit Breakers

Minimum oil circuit breakers have generally displayed a high level of reliability and performance.

The key issues associated with minimum oil circuit breakers include the following:

- maintenance intensive when compared with modern equivalent circuit breakers;
- circuit breakers that are required to perform a large number of operations (for example, those used in capacitor bank switching) develop severe contact erosion and need to be maintained frequently. Modular designs of minimum oil CBs have a number of interrupters in series. Over time, drive linkages have corroded. This event increases the friction in operation and drive insulators have sheared accordingly. Also, grading capacitors are prone to leakage;
- excessive corrosion of flanges and mortar cracking leading to drive rod insulator failures on older [C.I.C] 220 kV units;
- increasing spring mechanism failures and defects observed; and
- increasing cost and difficulty in obtaining spares and manufacturers support.

5.2.1 SF_6 Circuit Breakers

SF_6 circuit breakers have mainly suffered from SF_6 leaks and hydraulic mechanism problems including oil leaks, entrained gas, and trapped metal particle problems. Also, accumulators have suffered nitrogen losses. While the interrupting internal components are generally in excellent condition there are some design problems with broken resistor switch drives ([C.I.C]).

At lower voltages, where the circuit breakers are simpler, the internal reliability has been good. The trend towards arc-assisted puffer circuit breakers has resulted in simpler and more reliable mechanisms with a greater need for accurate knowledge of system operating conditions to ensure that the circuit breakers can close or interrupt reliably. Many of the older circuit breakers have reached their half-life age and gas leaks and the hardening of seals have become an increasing problem.

With the outsourcing of maintenance, costs have increased for non-standard work. SF_6 circuit breakers were purchased with the knowledge that a 'half-life' refurbishment would be necessary. This work is essentially a full strip-down with all seals replaced. Corrosion has proven worse than anticipated and SF_6 leaks are the most common cause of SF_6 circuit breaker system incidents, followed by hydraulic drive problems. Rather than the refurbishment costing between 10 and 20 per cent of the new cost, costs can reach 50 per cent or more. It is generally uneconomic to confirm the ratings of refurbished equipment by specific or type testing, as such refurbished equipment rarely has a service warrantee and remaining service life is uncertain. Diligent business case development means these factors frequently demonstrate little economic benefit in refurbishment compared with replacement with new equipment.

6 Risk Assessment

AusNet Services uses a range of techniques to assess risk and thus determine the replacement requirements for each asset class. These techniques include dependability management methodology and modelling, engineering review of condition assessment data, calculation of long run sustainability based on expected asset life and total population of assets, assessment of projects in progress and engineering knowledge of assets and the operational environment. The various techniques are applied depending on the asset type and the asset data available. The range of resulting risk assessments and replacement forecasts are compared, contrasted and brought together using engineering judgement to inform the management of risk and development of the replacement forecast.

6.1 Dependability Management

Dependability management brings together asset condition data, asset failure rates and the cost impact of asset failure to determine economic replacements. The dependability management program employs Availability Workbench software to provide an economic analysis of terminal station assets over a ten-year period.

This section summarises the reliability modelling of circuit breakers located within terminal stations. It sums the probabilistic replacements and equivalent risk costs and identifies the economic circuit breaker replacements or refurbishments required to prudently maintain failure risks. Key inputs to this dependability process are asset condition, remaining service potential (RSP%), failure rate and the effects of asset failure.

The following scenarios demonstrated are:

- Run to Failure[10]
- Risk Optimised Scenario.

Please refer to AMS 20-11 Dependability Management for more detail on the dependability management methodology.

6.1.1 Run to Failure Scenario[10]

A total life cycle cost of [C.I.C] comprising the impact of loss of supply on customers, health & safety costs, environment costs, collateral damage costs and reactive circuit breaker replacement costs (labour, equipment and spare) are shown in **Error! Reference source not found.**.

[10] Replace on condition where there is no economically significant safety or environmental impact in relation to the optimised maintenance or replacement of an asset.

[C.I.C]

Error! Reference source not found. shows that a run to failure strategy would result in a total effect cost (loss of supply costs, health & safety costs and environment costs) of [C.I.C] over the next 10 year period. This effect cost is disproportionate to the corrective maintenance (replacement) costs of approximately [C.I.C]. This effect cost is largely distributed between those assets assessed as in deteriorated condition; Condition 4 or Condition 5.

Over the 10 year period, reliability modelling suggests that a run to failure strategy would result in 222 circuit breaker failures with associated corrective maintenance (replacement) costs of [C.I.C] (labour, equipment and spare purchases) over the 10 year period.

The run to failure scenario does not include preventative maintenance (planned replacement) of circuit breakers; it demonstrates the minimum costs required to maintain service from this fleet of assets following in-service failures. It does not represent the minimum life cycle cost and is subsequently not recommended as the most efficient use of limited resources. This scenario is not the most prudent investment for customers and is presented here for comparison with a risk optimised scenario described in the next section.

6.1.2 Risk Optimised Scenario

The risk optimised scenario considers replacing assets where the combination of effects and corrective maintenance costs associated with asset failure outweighs the cost of planned replacement. **Error! Reference source not found.** shows a [C.I.C] total life cycle cost for the risk optimised management of circuit breakers over the next ten years. It shows a significant [C.I.C] reduction in the total impact on customers and corrective maintenance costs compared with the run to failure scenario:

[C.I.C]

Comparison of **Error! Reference source not found.** and **Error! Reference source not found.** shows selective replacement of 361 circuit breakers primarily in Condition 3, Condition 4 and Condition 5, will increase replacement costs from [C.I.C] over the ten year period and provide a significant reduction in the effect cost from [C.I.C].

Reliability modelling demonstrates that a Risk Optimised Scenario is the most economic use of limited resources and provides a significantly lower life cycle cost to customers. The Risk Optimised Scenario represents the minimum life cycle cost for circuit breakers and is recommended as the most efficient use of limited resources and a prudent investment for customers.

6.1.3 Dependability Management Replacement Forecast

AusNet Services is managing the risk for those assets in Condition 1, 2 and 3 unless otherwise required due to conditional replacement. Of the remaining Condition 4 and Condition 5 assets, 344 circuit breakers are considered economic for optimised replacement based on the effects to the community.

The circuit breaker asset fleet consists of 369 circuit breakers in Condition 4 and 74 circuit breakers in Condition 5. It is considered prudent to forecast replacement of the remaining 48 Condition 5 assets that are approaching end of life and are expected to require replacement within 6.75 years based on the modelling.

Replacement of 344 circuit breakers over a period of 10 years approximately equates to 34 circuit breakers per year or 172 circuit breakers during a five year period. It is planned to replace approximately 53 circuit breakers during next five years under the station rebuild / major asset replacement projects. The remaining 119 circuit breakers need to be replaced under a separate like for like program across multiple sites.

7 Strategies

This section details the high-level strategies based on a circuit breaker fleet management approach. The overall approach involves treating those circuit breakers which represent a high risk of failure generally driven by their very poor condition (C5), and poor condition (C4).

7.1 New Installations

- Install SF_6 live tank circuit breakers for 275 kV and above operating voltages and capacitor bank circuit breakers.
- Install SF_6 dead tank circuit breakers for 66 kV and 220 kV operating voltages.
- Install SF_6 dead tank circuit breakers for 22 kV AIS installations.
- Install Vacuum circuit breakers for non-GIS metal clad switchboards.

7.2 Inspection

- Continue to closely monitor the performance of SF_6 CBs with high operating duties.

7.3 Maintenance

- Salvage parts from replaced [C.I.C] 220 kV CBs and [C.I.C] 66 kV CB's to provide additional spares to support the diminishing fleet, especially spare bushings. Salvage a complete 66 kV [C.I.C] CBs to provide like spares for quick change-out.
- Salvage appropriate parts from replaced minimum oil CBs to provide critical spares for remaining members of the fleet.
- Continue to repair SF_6 leaks in a timely manner.

7.4 Refurbishment

- Carry out a program to refurbish [C.I.C] circuit breakers within the next seven years.
- Review the performance of older SF_6 CBs and develop economic refurbishment programs as required
- Continue to refurbish good performing SF_6 Cap Bank CBs before wear out.

7.5 Replacement

7.5.1 Bulk Oil Circuit Breakers

AusNet Services has commenced a replacement program for 220 kV bulk oil circuit breakers and selected replacement of critical 66 kV bulk oil units due to safety, reliability and environmental risks. The staged replacement of 220 kV bulk oil circuit breakers at Hazelwood power station switchyard is progressing (X920 project completed replacement of five bulk oil CBs and XB56 is in progress to replace another 11 bulk oil CBs). In addition, seven bulk oil circuit breakers were replaced at Rowville (X926) and four at Dederang terminal stations (XA03). Two projects are in progress to replace nine 220 kV bulk oil CBs at Ringwood terminal station (XB54) in 2015 and seven 220 kV bulk oil CBs at Hazelwood power station switchyard (XC28) in 2018. After implementation of these projects there will be no 220 kV bulk oil CBs in the Victorian transmission network.

Planned replacement will see the majority of these CBs replaced in the next few years. Maintenance, tailored to remaining service life, will ensure that the CBs are capable of performing their normal duty and remain in a safe state for operation. In view of the worsening thermal performance of some CBs with a history of overload, priority is to be given to replacing CBs on connections where the thermal performance is marginal. Oil filled EHV bushings shall be given regular (nominally four-yearly) DGA and moisture tests on their oil.

A program is in place to salvage parts from replaced [C.I.C] 220 kV circuit breakers and [C.I.C] 66 kV circuit breakers in order to generate spares. Bushings of the [C.I.C] circuit breakers are electrically tested to ensure the bushings are serviceable. All the 66 kV bulk oil CBs at West Melbourne Terminal Station (WMTS), will be replaced and 22 kV CBs will be retired with the station rebuild program (XA14) by 2022/23.

A program has been implemented to analyse oil samples taken from the interrupter tanks of bulk oil CBs to assess contact wear. Samples are taken during scheduled maintenance of the CB so that the condition of the oil can be observed. Oil analysis checks both the condition of the oil and for the presence of wear metals and is used as a guide to adjust future maintenance intervals. For example, an abnormal ratio between acetylene and ethylene gases may indicate excessive arcing in the CB interrupting chamber.

- Prioritise the replacement of 220 kV [C.I.C] circuit breakers on the basis of risk within the next seven years.
- Prioritise the replacement remaining 66 kV and 22 kV bulk oil circuit on the basis of risk within in the next 15 years.

7.5.2 Minimum Oil Circuit Breakers

Minimum oil CBs form two general groups. The first group comprises 11 older CBs in poor condition, such as [C.I.C] and [C.I.C] CBs, the majority of which are candidates for replacement within next seven years. These are treated in the same way as bulk oil CBs except that specific bushing DGA testing is not required because of the lower volumes of oil in the interrupting chambers.

The second group of CBs mostly involves multiple interrupter units. These will continue to be maintained on a time or I^2t basis as at present. It is not economic, and present performance indicates that it is not necessary, to provide additional condition monitoring. A program is also established for the replacement of a number of relatively modern minimum oil circuit breakers. That is, those that have been on capacitor bank or reactor switching duty, this is because of the high contact erosion in service.

Where station rebuilds are undertaken, minimum oil CBs will be replaced where they do not have adequate long-term normal current and fault rating.

- Prioritise the replacement of 220 kV minimum oil CBs; the [C.I.C] on the basis of risk within seven years.
- Prioritise replacement of 220 kV minimum oil CBs in poor condition; [C.I.C] and [C.I.C] type on the basis of risk within the next seven years.
- Prioritise the Replacement of the 66 kV [C.I.C] CBs on the basis of risk within next seven years.
- Prioritise replacement of [C.I.C] CBs in poor condition on the basis of risk within next seven years.
- Where economic replace minimum oil circuit breakers used for reactor or capacitor switching duty with high operations with SF_6 CBs.
- Include the replacement of minimum oil circuit breakers in station rebuild projects where normal and fault current ratings are forecast to be inadequate. Prioritise replacement of minimum oil CBs based on the following criteria:
    - failure risk;
    - sustained history of performance and maintenance issues;
    - number of operations; and
    - those that lack critical spares.

7.5.3 SF_6 Circuit Breakers

All SF_6 CBs are fitted with some facility for monitoring SF_6 pressure and mechanism condition.

Changing SF_6 gas pressures that would threaten the correct operation of the CB are alarmed remotely. Provided the condition of these CBs does not worsen, there is no need to retrofit further condition monitoring. Future actions may involve the better monitoring of existing alarms and indications (as has been proposed for new SF_6 CBs). Particularly for AIS SF_6 CBs or mechanisms, it is more effective to rectify problems than it is to improve the monitoring that facilitates early attention to symptoms. Only in the case of GIS, may it be economic to retrofit continuous indication, gas density monitors rather than repairing leaks by changing over units in AIS.

Air insulated or gas insulated SF_6 CBs that require major repair (SF_6 leaks or mechanisms) will have major component assemblies removed to a suitable facility. Replacement of a unit from the larger populations will create spares for refurbishment works. For small populations of SF_6 CBs; failed units may have to be repaired *in situ* using existing spares.

Where it has been demonstrated that repairs or half-life rebuilds are uneconomic, consideration will be given to complete replacement of CBs with modern SF_6 CBs (with comparable or better performance).

- Where economic replace poor performing SF_6 Cap Bank CBs such as [C.I.C] type before second wear out refurbishment.

7.5.4 Vacuum Circuit Breakers

All the 22 kV Vacuum CBs in transmission asset fleet are relatively new (less than 10 years) and are generally in good condition. One of the problems associated with Vacuum CBs is the loss of vacuum in their interrupter chambers after some operations and years of service.

- Monitor developments of vacuum technology at 66 kV and where economic introduce SF_6 free CBs into the network.

8. Appendix A – Circuit Breaker Listing by Type

The following tables provide a summary of transmission circuit breakers by manufacturer and type.

[C.I.C]

CB Type	Station	500 kV	330 kV	275 kV	220 kV	66 kV	22 kV	6.6 kV	4.5 kV	Total
SF6	ATS	0	0	0	8	18	0	0	0	26
	BATS	0	0	0	9	10	0	0	0	19
	BETS	0	0	0	10	14	0	0	0	24
	BLTS	0	0	0	9	6	0	0	0	15
	BTS	0	0	0	2	0	2	0	0	4
	CBTS	3	0	0	12	14	0	0	0	29
	DDTS	0	10	0	11	0	0	0	0	21
	EPSY	0	0	0	7	0	0	0	0	7
	ERTS	0	0	0	3	10	0	0	0	13
	FBTS	0	0	0	6	3	0	0	0	9
	FTS	0	0	0	0	1	0	0	0	1
	GNTS	0	0	0	2	2	0	0	0	4
	GTS	0	0	0	14	18	0	0	0	32
	HOTS	0	0	0	7	9	0	0	1	17
	HTS	0	0	0	0	5	0	0	0	5
	HWPS	0	0	0	13	0	0	0	0	13
	HWTS	15	0	0	0	0	0	0	0	15
	HYTS	4	0	4	0	0	0	0	0	8
	JLTS	0	0	0	6	0	0	0	0	6
	KGTS	0	0	0	8	10	2	0	1	21
	KTS	7	0	0	27	26	0	0	0	60
	LYPS	18	0	0	0	0	0	0	0	18
	MBTS	0	0	0	10	4	0	0	0	14
	MLTS	9	0	0	13	0	0	0	0	22
	MTS	0	0	0	4	10	0	0	0	14
	MWTS	0	0	0	0	16	0	0	0	16
	RCTS	0	0	0	11	12	3	0	0	26
	ROTS	2	0	0	31	0	2	0	0	35
	RTS	0	0	0	3	13	0	0	0	16
	RWTS	0	0	0	8	14	2	0	0	24
	SHTS	0	0	0	11	10	0	0	0	21
	SMTS	0	8	0	6	14	0	0	0	28
	SVTS	0	0	0	1	4	0	0	0	5
	TBTS	0	0	0	6	6	0	0	0	12
	TGTS	0	0	0	6	12	0	0	0	18
	TRTS	3	0	0	0	0	0	0	0	3
	TSTS	0	0	0	6	3	0	0	0	9
	TTS	0	0	0	25	8	0	0	0	33
	WBTS	0	0	0	2	2	0	0	0	4
	WETS	0	0	0	1	3	0	0	0	4
	WMTS	0	0	0	3	3	0	0	0	6
	WOTS	0	4	0	0	0	0	0	0	4
	YPS	0	0	0	3	0	0	0	0	3
BULK OIL	BLTS	0	0	0	0	14	2	0	0	16
	ERTS	0	0	0	0	14	0	0	0	14
	FBTS	0	0	0	0	12	0	6	0	18
	FTS	0	0	0	0	7	0	0	0	7
	GNTS	0	0	0	0	6	0	0	0	6
	GTS	0	0	0	0	6	0	0	0	6
	HOTS	0	0	0	0	5	0	0	0	5
	HTS	0	0	0	0	11	0	0	0	11
	HWPS	0	0	0	19	0	0	0	0	19
	KGTS	0	0	0	0	0	1	0	0	1
	MWTS	0	0	0	0	3	0	0	0	3
	RCTS	0	0	0	0	0	3	0	0	3
	ROTS	0	0	0	4	0	0	0	0	4
	RTS	0	0	0	0	7	22	0	0	29
	RWTS	0	0	0	5	6	2	0	0	13
	SHTS	0	0	0	0	9	0	0	0	9
	SVTS	0	0	0	0	17	0	0	0	17
	TSTS	0	0	0	0	13	0	7	0	20
	TTS	0	0	0	0	16	0	0	0	16
	WMTS	0	0	0	0	13	15	0	0	28

Circuit Breakers

MIN OIL	BETS	0	0	0	0	2	0	0	0	2
	BLTS	0	0	0	4	5	0	0	0	9
	DDTS	0	2	0	0	0	0	0	0	2
	ERTS	0	0	0	2	1	0	0	0	3
	FBTS	0	0	0	1	3	0	0	0	4
	GNTS	0	0	0	0	1	0	0	0	1
	GTS	0	0	0	0	1	0	0	0	1
	HTS	0	0	0	2	0	0	0	0	2
	HWPS	0	0	0	2	0	0	0	0	2
	JLTS	0	0	0	2	0	0	0	0	2
	KGTS	0	0	0	0	0	2	0	0	2
	LY	0	0	0	0	16	0	0	0	16
	MWTS	0	0	0	0	12	0	0	0	12
	RCTS	0	0	0	0	2	0	0	0	2
	ROTS	0	0	0	4	0	0	0	0	4
	RTS	0	0	0	4	3	0	0	0	7
	RWTS	0	0	0	0	2	0	0	0	2
	SMTS	0	1	0	0	0	0	0	0	1
	SVTS	0	0	0	4	1	0	0	0	5
	TBTS	0	0	0	0	7	0	0	0	7
	TSTS	0	0	0	0	2	0	0	0	2
	TTS	0	0	0	0	4	0	0	0	4
	WMTS	0	0	0	5	1	0	0	0	6
	WOTS	0	0	0	0	6	0	0	0	6
	YPS	0	0	0	19	0	0	0	0	19
VACUUM	BTS	0	0	0	0	0	23	0	0	23
	MTS	0	0	0	0	0	11	0	0	11
AIR BREAK	FBTS	0	0	0	0	0	0	1	0	1
	TSTS	0	0	0	0	0	0	1	0	1
AIR BLAST	GNTS	0	0	0	7	0	0	0	0	7

9. Appendix B – Circuit breaker Significant Failure History

The following table provides details of circuit breaker significant failures experienced from 1997 to 2014.

Incident Date	Station	kV	CB Manuf.	CB Designation	Technology	Duty	Age (years) at time of failure	Nature of Failure	Remedial Action
13/12/1997	HWPS	220	[C.I.C]	[C.I.C]	Bulk oil	Transf./Line/Bus Tie	26	Bushing explosion with collateral damage. Insulation deterioration accelerated due to low oil level.	Replaced failed and damaged bushings.
24/01/2000	HTS	220	[C.I.C]	[C.I.C]	Minimum Oil	Transf./Line/Bus Tie	34	Partial close operation. Drive insulators fractured.	Replaced broken drive insulators. Class 2 overhaul on interrupters
07/02/2001	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.
01/03/2001	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.
03/09/2001	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.
19/04/2002	KTS	220	[C.I.C]	[C.I.C]	Minimum Oil	Transf./Line/Bus Tie	40	Partial close operation. Drive insulators fractured.	Replaced broken drive insulators. Class 2 overhaul on interrupters

Incident Date	Station	kV	CB Manuf.	CB Designation	Technology	Duty	Age (years) at time of failure	Nature of Failure	Remedial Action
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
04/02/2003	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.
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.
04/10/2004	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.
06/06/2005	ROTS	220	[C.I.C]	[C.I.C]	Bulk oil	Transf./Line/Bus Tie	32	High Resistance joint developed internal to bushing head causing significant overheating.	Replaced bushing.

Incident Date	Station	kV	CB Manuf.	CB Designation	Technology	Duty	Age (years) at time of failure	Nature of Failure	Remedial Action
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 [C.I.C] on network programmed for replacement.
25/08/2006	DDTS	220	[C.I.C]	[C.I.C]	Bulk oil	Transf./Line/Bus Tie	36	Internal flashover and explosion. Permanent deformation of tank and expulsion of some hot oil.	Complete CB replaced with modern SF_6 CB
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.
10/10/2006	ERTS	66	[C.I.C]	[C.I.C]	SF_6 – Live tank	Cap Bank	11	Catastrophic failure during opening operation to de-energise Cap Bank. Investigations revealed an early wear out failure at 2400 operations (compared to manual of 4000 operations).	Complete CB replaced. Policy change and Operation limit for type reduced to 1800 operations. Refurbishment program ignited for CB forecast to reach 1800 ops within 2 years.
16/07/2007	ROTS	220	[C.I.C]	[C.I.C]	Bulk oil	Transf./Line/Bus Tie	34	High Resistance joint developed internal to bushing head causing significant overheating.	Replaced bushing.
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.

Incident Date	Station	kV	CB Manuf.	CB Designation	Technology	Duty	Age (years) at time of failure	Nature of Failure	Remedial Action
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. CB switches a Cap Bank.	Complete CB replaced with same type. Integrity of the fleet of same type checked by [C.I.C].
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.
20/05/2008	MLTS	500	[C.I.C]	[C.I.C]	SF_6 – Live tank	Transf./Line/Bus Tie	25	Sudden major SF_6 leak developed - weekly top up required. Internal corrosion at Pre-insertion resistor caps.	Replaced head with spare. Repaired removed unit. Refurbished further head to confirm if one off or generic problem.
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	During maintenance, mechanism seized, and could not operate. Investigations suspected accidental overcharging during maintenance.	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
16/10/2008	HWPS	220	[C.I.C]	[C.I.C]	Bulk oil	Transf./Line/Bus Tie	37	High Resistance joint developed internal to bushing head causing significant overheating.	Replaced bushing.
11/12/2008	MWTS	66	[C.I.C]	[C.I.C]	Minimum Oil	Transf./Line/Bus Tie	25	Mechanism components broken and frame damaged. Due to loss of damping and wear out adjustment.	Complete mechanism replaced.
05/04/2009	MWTS	66	[C.I.C]	[C.I.C]	Bulk oil	Transf./Line/Bus Tie	41	Burn out of solenoid mechanism.	Complete mechanism replaced.
07/04/2009	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 wear 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 [C.I.C] 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.
09/02/2010	HWPS	220	[C.I.C]	[C.I.C]	Bulk oil	Transf./Line/Bus Tie	39	High Resistance joint developed internal to bushing head causing significant overheating.	Replaced bushing.

Incident Date	Station	kV	CB Manuf.	CB Designation	Technology	Duty	Age (years) at time of failure	Nature of Failure	Remedial Action
22/03/2010	BLTS	220	[C.I.C]	[C.I.C]	Minimum Oil	Transf./Line/Bus Tie	35	Partial close operation, external linkages seized causing drive insulators fracture.	Replace broken drive insulators. Improved maintenance regime.
09/06/2010	GTS	66	[C.I.C]	[C.I.C]	SF_6 – Live tank	Cap Bank	10	Failure to clear current during opening operation to de-energise Cap Bank. Bus Protection operated preventing catastrophic failure of CB. Investigations revealed an early wear out failure at 1830 operations (compared to internal revised limit of 1800 operations).	Complete CB replaced. Policy change and Operation limit for type reduced to 1000 operations.
09/11/2010	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 investigations could find no root cause. Approx 1600 operations	Complete CB replaced.
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	Maintenance check discovered unacceptable SO2 levels, indicating excessive arcing. Later investigations found wear out and slack internal drive rod. CB had performed 1500ops.	Complete CB replaced.

Incident Date	Station	kV	CB Manuf.	CB Designation	Technology	Duty	Age (years) at time of failure	Nature of Failure	Remedial Action
28/12/2010	HWPS	220	[C.I.C]	[C.I.C]	SF_6 – DT or GIS	Generator	6	Flashed over to earth following an unsynchronised close and immediate trip signal from Generator. Investigations suspect 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. Leak from drive crankcase and could not be repaired in situ.	Complete CB replaced.
01/04/2011	HTS	66	[C.I.C]	[C.I.C]	SF_6 – Live tank	Cap Bank	14	Mechanism components broke, resulting in failure of mechanism to open or close CB. CB duty is on a high operation cap bank. Mechanism > 2000 operations.	Complete mechanism replaced.
06/04/2011	BTS	22	[C.I.C]	[C.I.C]	SF_6 – DT or GIS	Cap Bank	11	Flashover to enclosure while CB was open and energised on bus side. Cubicle failure due to moisture entry.	Enclosure resealed and additional heaters installed.
09/05/2011	BTS	22	[C.I.C]	[C.I.C]	SF_6 – DT or GIS	Cap Bank	11	Flashover to enclosure while CB was open and energised on bus side. Cubicle failure due to moisture build up.	Enclosure resealed and additional heaters installed.
16/05/2011	TTS	220	[C.I.C]	[C.I.C]	Bulk Oil	Transf./Line/Bus Tie	37	High Resistance joint developed internal to bushing head causing significant overheating.	Replaced bushing.
17/05/2011	HWPS	220	[C.I.C]	[C.I.C]	Bulk Oil	Transf./Line/Bus Tie	40	High Resistance joint developed internal to bushing head causing significant overheating.	Replaced bushing.

Incident Date	Station	kV	CB Manuf.	CB Designation	Technology	Duty	Age (years) at time of failure	Nature of Failure	Remedial Action
29/07/2011	TTS	220	[C.I.C]	[C.I.C]	SF_6 – Live tank	Cap Bank	10	During maintenance discovered unacceptable high SO2, a by-product of excessive arcing. Loose interphase linkages due to lack of locking washers. Later internal investigation found damaged nozzle. CB switches a high operation Cap Bank.	Complete CB replaced.
31/08/2011	BLTS	220	[C.I.C]	[C.I.C]	Minimum Oil	Transf./Line/Bus Tie	36	Failure to close on one phase as mechanism seized through internal corrosion.	Replaced broken drive insulators. Class 2 overhaul on interrupters.
30/09/2011	YPS	220	[C.I.C]	[C.I.C]	Minimum Oil	Transf./Line/Bus Tie	32	Partial close operation. Mechanism failed and broken parts due to sticking mechanism.	Complete mechanism and pole (with interrupters) replaced.
29/05/2012	KTS	220	[C.I.C]	[C.I.C]	SF_6 - DT or GIS	Transf./Line/Bus Tie	4	Flashover to tank shortly after closing and putting Line on load.	Investigation pending.
22/03/2013	HWPS	220	[C.I.C]	[C.I.C]	Bulk Oil	Transf./Line/Bus Tie	44	Operating shaft impeding operation of CB phase.	Shaft guide loosened to remove mechanical impedance.
31/03/2013	FBTS	66	[C.I.C]	[C.I.C]	Bulk Oil	Transf./Line/Bus Tie	42	Bushing failure – fault had caused bushing to separate from the interrupter tank.	Bushing replaced.
02/03/2013	JLTS	220	[C.I.C]	[C.I.C]	Minimum Oil	Transf./Line/Bus Tie	33	Broken tension chain prevented operation of the mechanism.	Chain replaced and mechanic realigned.
24/01/2013	TTS	220	[C.I.C]	[C.I.C]	SF_6 - live tank	Cap Bank	28	Dampers were damaged resulting in an inability to charge the closing springs.	Dampers replacement.

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19/11/2014	ROTS	220	[C.I.C]	[C.I.C]	SF_6 - live tank	Cap Bank	19	CB had tripped a number of times due to the mechanism tripping free, but was able to be switched back in. On this occasion pole C would not latch.	Trip spring was tightened to slow down the closing speed of pole C allowing the mechanism time to latch.