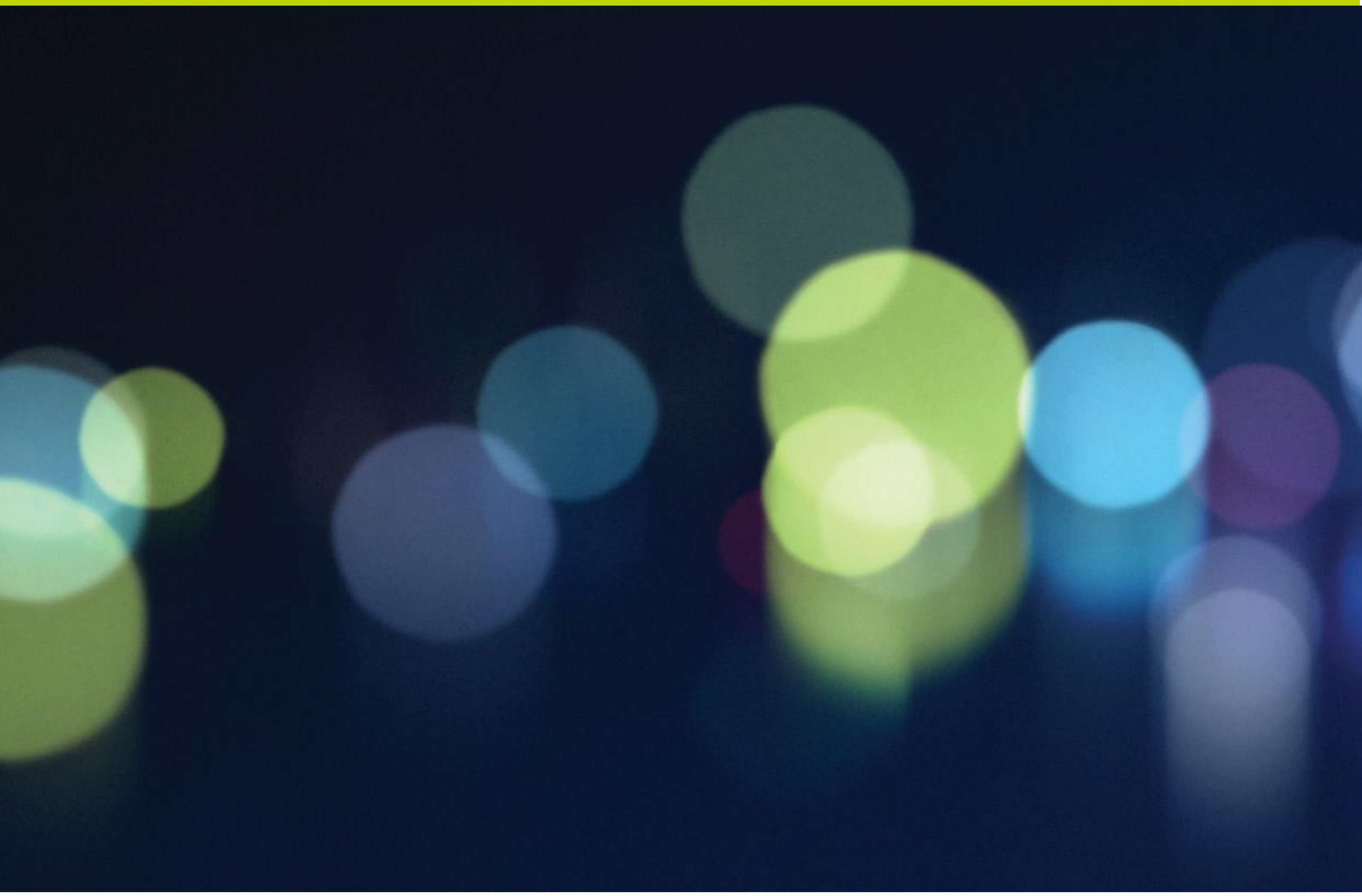
Circuit Breakers Asset Class Plan

Substation Assets

November 2022



Endeavour Energy

Version control

Version	Date	Comments
1.0	Nov 2022	Initial Release

Contents

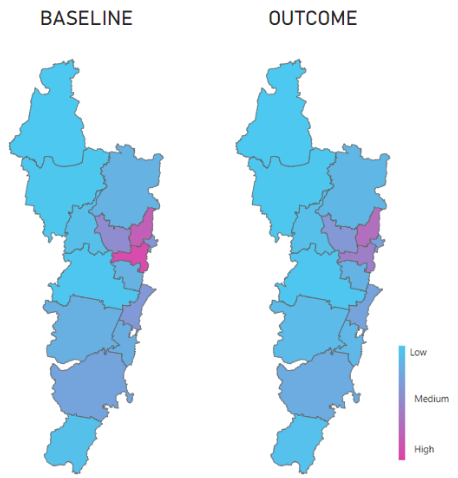
1. Executive Summary

A 10-year strategy for circuit breakers has been defined driven by the risk associated with the aging population of the asset class. The forecasted risk, strategy cost breakdown, and performance metrics are outlined below and include all Endeavour Energy owned circuit breakers ranging from 11kV to 132kV within the sub-transmission network.

Risk Forecast

The failure of circuit breakers in service may lead to safety, reliability and financial consequences. These consequences are quantified in monetary terms and coupled with statistical modelling to determine the optimal level of investment to manage the risk.

As these assets age, the risk associated with their failure in service also increases which is represented geographically by total risk within Endeavour depot locations.

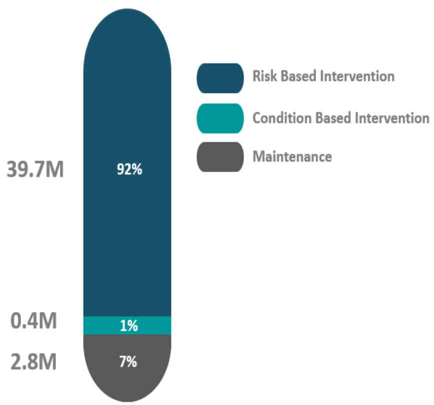


Strategy and Cost

The selected strategy to address the risk associated with circuit breakers is predominantly one of planned proactive replacement, with a small volume of reactive replacements in response to conditional and functional failures.

The strategy also includes the continuation of the current regime of routine preventative maintenance and condition-based maintenance.

The total cost of this strategy (in $ real FY23) for the 2023 - 2029 period is $40.1M for capital replacements and $2.8M for maintenance.



Key Performance Indicators

The performance objectives for the circuit breaker asset class and the current status of each of those objectives is shown in the table below.

Based on the 10-year strategy proposed in this asset class plan, the reliability performance indicator is expected to improve as the fleet of aged 11kV oil circuit breakers are replaced with vacuum trucks or vacuum switchboards. The safety indicator is currently compliant but is expected to improve further as oil circuit breakers are replaced with the safer vacuum (or SF6) technology. The environmental indicator requires the company or our customers to place a significant monetary value on SF6 gas pollution in order to drive the investment decisions needed to make an impact on this indicator.

Performance Category	Objective	Status
Asset Utilisation	To monitor and understand asset utilisation across each asset type and network wide to inform topology standards and maximise the utilisation of the existing asset base.	—
Safety	Reduce the number incidents (excluding general hazards)	●
Reliability	Reduce the number of unplanned outages associated with functional failures	●
Financial	Harmonise capital investment in the asset class to the forecast spend in AER REPEX model	●
	Maintain annual maintenance costs for the asset class	●
Environmental	SF6 leakage in CB's (kg) over the last five years	●
	Reduce the leakage of SF6 gas to atmosphere to support the company's Net Zero Emissions and Sustainability Linked Loan targets	●
Resilience	Monitor the average number of customers impacted during an unplanned outage	—

2. Overview

2.1 Purpose

The purpose of this document is to outline the asset management practices for the circuit breaker asset class and define a 10-year strategic plan for the class based on the risk the asset's present risk and the cost of replacement and refurbishment options.

The 10-year plan seeks to use current knowledge of the asset in the context of the whole electrical network to establish Key Performance Indicators (KPI) to assist in understanding and monitoring the ongoing performance of the asset. The adopted levels of service for circuit breakers are based on risk/benefit trade-offs versus cost of investment options, legislative requirements, customer expectations and strategic goals set by Endeavour Energy.

This document is intended to function as part of the "Performance Monitoring and Review Process" as established in the Asset Management System (AMS) outlined in Section 8 of this report. The document plays a key role in:

- Providing line of sight between the company's performance objectives and investments proposed for the circuit breaker asset class;
- Monitoring of the performance of the asset class against the set of performance indicators (KPI's);
- Establishing a link between the performance of individual circuit breakers and the performance of the asset class as a whole;
- Communication of the risks presented by the asset class and replacement costs (as indicated by the volume of asset replacements initiated by functional failures, condition-based replacements and risk-based replacements).

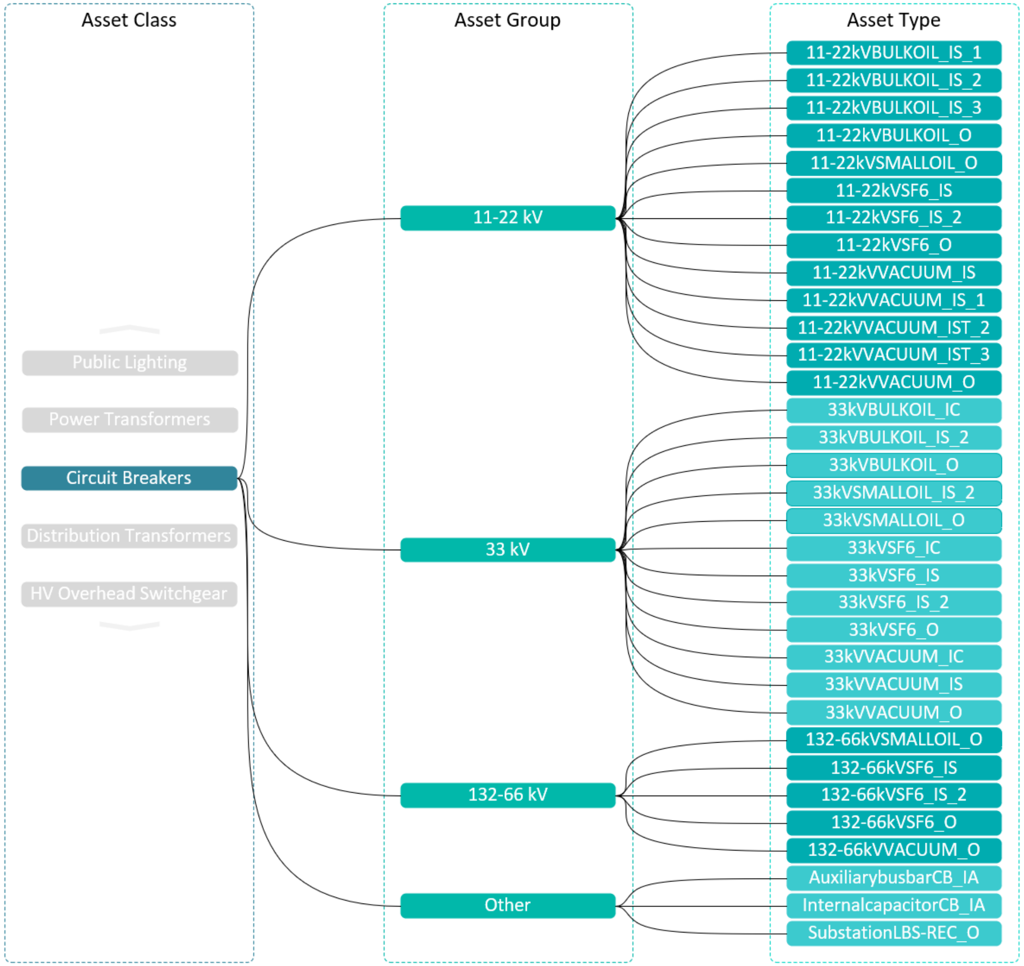
This document will highlight and discuss historical trends and future forecasts of risk and cost for a replacement strategy based on a mix of the following asset replacement approaches:

- Risk-based asset replacements (e.g. planned proactive replacements based on risk/cost justification);
- Condition-based asset replacements (e.g. replacements triggered by failure of the asset to meet applicable performance or condition standards. Usually identified during inspection and/or maintenance works);
- Functional asset failures (e.g. assets replaced after failure whilst in service).

The "baseline" risks outlined throughout this document represent the risk trend which is expected to be experienced in the absence of any planned proactive asset replacement strategy or program. The forecast "outcome" risk projections throughout this document are based on an optimal mix of the above investment approaches as proposed in the Case for Investments (CFI's) as well as the continuation of the existing maintenance strategies. In the case of HV circuit breakers, the proposed intervention strategy for the FY23-29 period is the planned proactive replacement of circuit breakers that are risk/cost justified.

2.2 Scope

This report covers all circuit breakers owned by Endeavour Energy at voltages of 132kV, 66kV, 33kV, 22kV and 11kV which are installed in zone and transmission substations, switching stations and customer substations.



Glossary

IS – Indoor Switchboard
O - Outdoors
IC – Indoor Chamber
IA – In Auxiliary Switchboard
LBS – Load Break Switch
REC - Recloser
IST – Indoor Switchboard Truck

3. Asset Portfolio

3.1 Asset Function

The purpose of circuit breakers is to allow the electrical network to be switched. Circuit breakers are designed to switch large currents including fault currents:

- automatically – when operated by a protection relay to isolate a fault;
- automatically by SCADA control to reconfigure the network to restore supply by an alternate path after a fault is isolated; and
- by manual control (via SCADA) to reconfigure the network to allow a section of the network to be isolated for maintenance or to transfer load from one part of the network to another.

The objective of the class of circuit breakers is to contribute to achieving the required standards of safety and reliability of the electricity supply.

The role and minimum performance measures for transmission circuit breakers is underpinned by Company Policy 9.2.5 - *Network Asset Design*. This policy states:

"The sub-transmission and distribution network assets will be designed so that they can be operated and maintained safely and within design parameters under normal and foreseeable abnormal situations. The designs of network assets and systems will be simple and robust and must be able to be protected by industry standard protection systems and managed using industry standard management practices."

The ratings requirements for circuit breakers are specified in Company Policy 9.2.10 – *Network Asset ratings*.

Further requirements for circuit breakers in the context of their host zone/transmission substation or switching station is provided in Substation Design Instruction 501 – *Subtransmission Network and Zone Substation Configuration*.

The breakdown of risks that are attributed to this asset class are shown in section 4 to illustrate performance measures and key drivers.

3.2 Asset Population

Endeavour Energy currently has a fleet of 4,487 individual circuit breakers in service at voltages of 132kV, 66kV, 33kV, 22kV and 11kV.

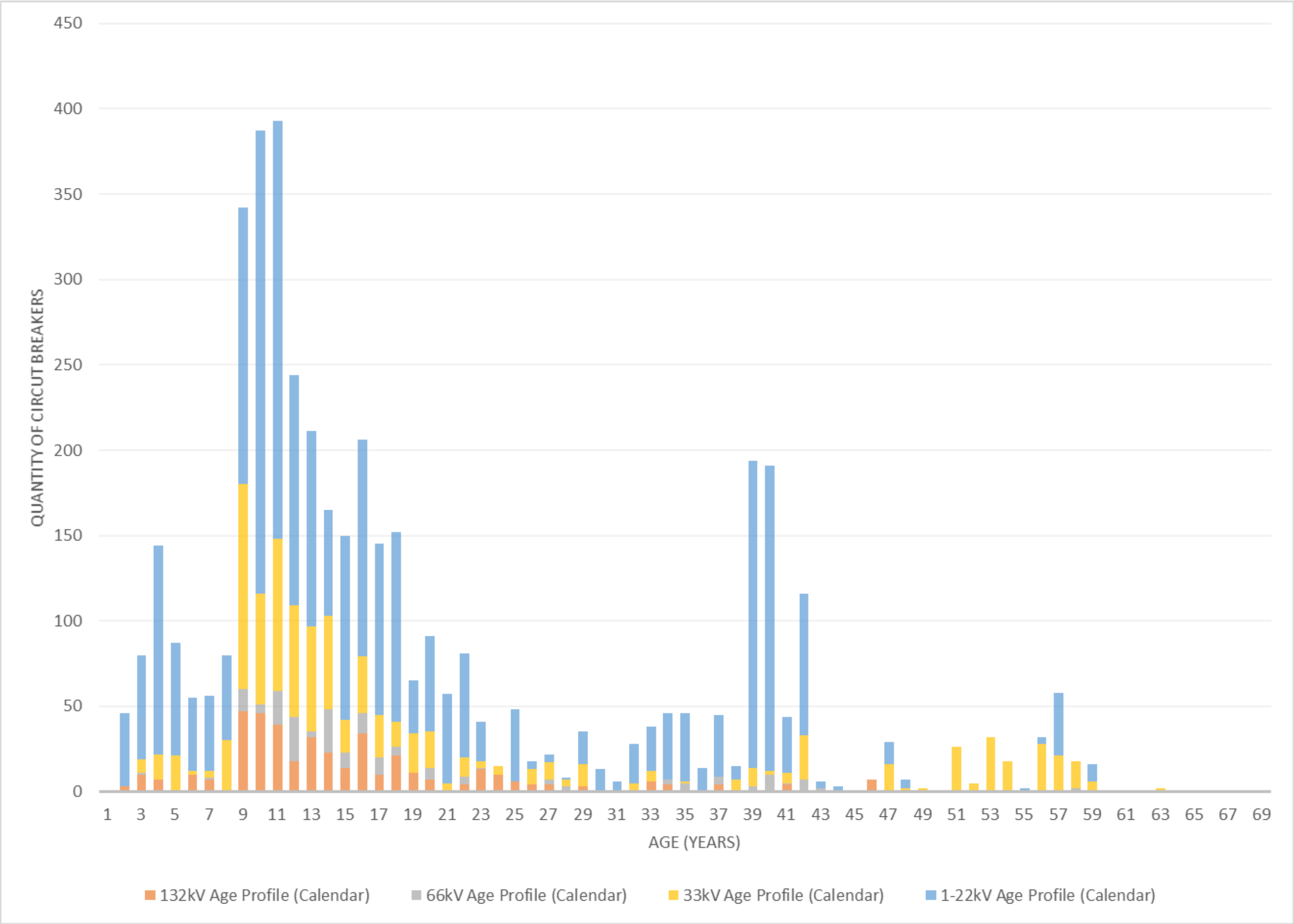
The circuit breakers use oil, SF_6 gas or vacuum for insulation and/or for quenching the electrical arc that forms during switching.

Many individual circuit breakers are part of indoor switchboards and in some cases, the switchboard is considered as the asset, rather than the individual circuit breakers.

The table below shows the breakdown of the fleet of individual circuit breakers by voltage and insulation/arc quenching medium.

Voltage (kV)	Insulating/arc-quenching medium				Totals
	Bulk oil	Small oil	SF_6	Vacuum	
132	-	16	397	-	413
66	-	27	158	1	186
33	208	8	130	626	972
22	-	-	3	55	58
11	500	2	284	2,072	2,858
Total	**708**	**53**	**972**	**2,754**	**4,487**

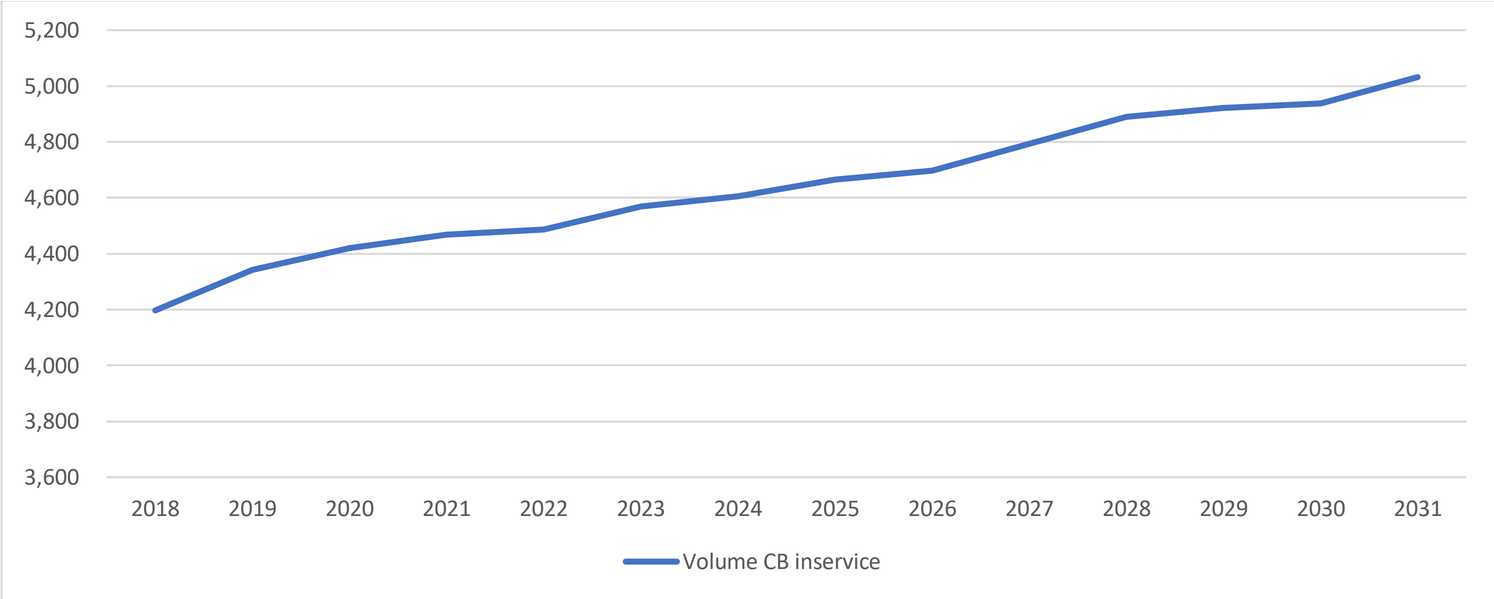
The current fleet of circuit breakers has been installed progressively as the network has expanded and been renewed over the last 60 or so years. The following figure shows the current age profile of the fleet of circuit breakers, in terms of their calendar age.



The total number of assets in the network has grown over the past 10 years as additional zone and transmission substations were added to the network to meet customer demand and as older substations were replaced with newer substations with increased capacity and hence larger numbers of circuits controlled by 11 and 22kV circuit breakers.

Looking forward, the trend of network expansion is expected to continue for a further 10 years or so in line with forecasts of new zone and transmission substation developments in new release areas. However, the renewal of aged circuit breaker equipment is now more likely to follow a trend of like-for-like replacement with modern equivalent equipment and therefore renewal will generally not add significantly to the number of assets on the network.

The figure below show the past trend of volume of installed circuit breakers and the forecast looking forward.



4. Asset Performance

This section quantifies the risks associated with circuit breaker failures and performance measures applicable to the asset class. The weighting for different risk categories indicates the areas of focus for managing the maintenance, life cycle and intervention options for this asset class. These are further broken down into performance measures that enable the relationships to be drawn between risk and the asset performance.

The consequences of failure of circuit breakers varies with the type of CB, the insulation it uses and its location in the network. Across the entire asset class, the range of consequences and proportion of the total risk presented by each is summarised in the table below. This risk profile is an average across the fleet of circuit breakers and will change as older oil insulated circuit breakers are replaced with modern vacuum insulated units which have reduced consequences of failure.

The largest risk by for this asset class is associated with reliability and is expected remain dominant for the foreseeable future.

Risk Category	Range of consequences	Risk Contribution (%)
Reliability	- Loss of supply to a varying number of customers supplied by the substation depending on where in the topology of the substation that the CB failure occurs, the customer demand and whether the CB is in a zone or transmission substation.	81
Financial	- Clean up of the failure, investigation and reporting, replacement of any adjacent equipment damaged by the failure and replacement of the failed asset in a reactive manner (providing the service of the asset is still required – which is generally the case).	18
Safety	- Safety risk to workers who may be in close proximity to the asset when it fails; - Risk with new vacuum and SF_6 circuit breakers and switchboards is very low – meets the criteria of as low as reasonably practicable (ALARP). Modern indoor switchboards with arc-fault containment and arc-fault ducting also meet the criteria of the safety risk having been eliminated as far as is practicable (SFAIRP); - Risk of fatality or serious injury due to workers near to oil-filled circuit breakers due to explosion and oil fire including being struck with pieces of porcelain insulators is moderate and accounts for the risk contribution. Generally these risks are ALARP and don't present sufficient economic value to have a significant influence on the timing of the replacement intervention.	1
Bushfire	- Nil material risk – failures are invariably contained within switchyard or control building spaces.	0
Environmental	- Nil material risk – the expulsion of a small volume of oil and the creation of smoke and fumes in the event of an explosive failure of an oil CB creates a low level of environmental pollution for a short-term period of time. However, there are no fines or monetised values placed on this and therefore the economic risk is considered to be zero.	0

Risk Category	Range of consequences	Risk Contribution (%)
	- The failure of a CB insulated with SF_6 *may* result in SF_6 escaping to the atmosphere which is an environmental impact. However, at present there are no fines for this and the AER and the electricity industry does not place a monetary value on global warming potential of this occurrence this and therefore the economic risk is considered to be zero. Note that this is likely to change in the short-term, driven by Company policy and objectives of achieving net zero emissions and subsequent financing arrangements, and therefore, the potential risk presented by SF_6 circuit breakers is included in the cost benefit assessment, but currently given zero value.	

The table below summarises the asset performance service level and objectives across the fleet of circuit breakers.

Performance Category	Objective	Performance Measure	Asset Type	Current Performance	Performance Target	Status	Trend
Asset Utilisation	To monitor and understand asset utilisation across each asset type and network wide to inform topology standards and maximise the utilisation of the existing asset base.	% of faults successfully cleared over the total number of faults seen by the CB population	All	Not currently recorded	-	—	—
Safety	Reduce the number incidents (excluding general hazards)	5-year rolling average of total incidents (excluding general hazards)	11-22kV	0.0	Maintain low no. of safety incidents	●	—
			33kV	0.0			
			66-132kV	0.0			
Reliability	Reduce the number of unplanned outages associated with functional failures	5-year rolling average of unplanned outages	11-22kV	1.4	Reduce in line with forecasts	●	—
			33kV	0.0			
			66-132kV	0.0			
Financial	Maintain annual maintenance costs for the asset class	10-year rolling average of maintenance costs	All	$0.4M	Maintain	●	—
Environmental	Reduce the leakage of SF6 gas to atmosphere to support the company's Net Zero Emissions and Sustainability Linked Loan targets	SF6 leakage in CB's (kg) over the last five years	SF6 only	65kg	Maintain	●	—
		% of average annual leaked SF6 gas (over 5 years) to the total mass of SF6 gas in CB population		0.2%	Reduce	●	—
Resilience	TBC	TBC	All	TBC	TBC	—	—

4.1 Asset Utilisation

4.1.1. Objective

To monitor and understand asset utilisation across each asset type and network wide to inform topology standards and maximise the utilisation of the existing asset base.

4.1.2. Performance

There is no current performance measure for the utilisation of HV circuit breakers.

4.1.3. Gap

At present, a performance measure for the utilisation of HV circuit breakers has not been developed, however, a proposed measure is to record the number of faults successfully cleared by the HV circuit breaker asset population.

4.1.4. Response

In order to develop this performance measure, a workflow will need to be generated to gather data and continuously monitor faults seen by HV circuit breakers from SCADA and ADMS.

4.2 Safety

4.2.1. Objective

Stabilise, monitor, and maintain safety risk across the asset base over the following regulatory period.

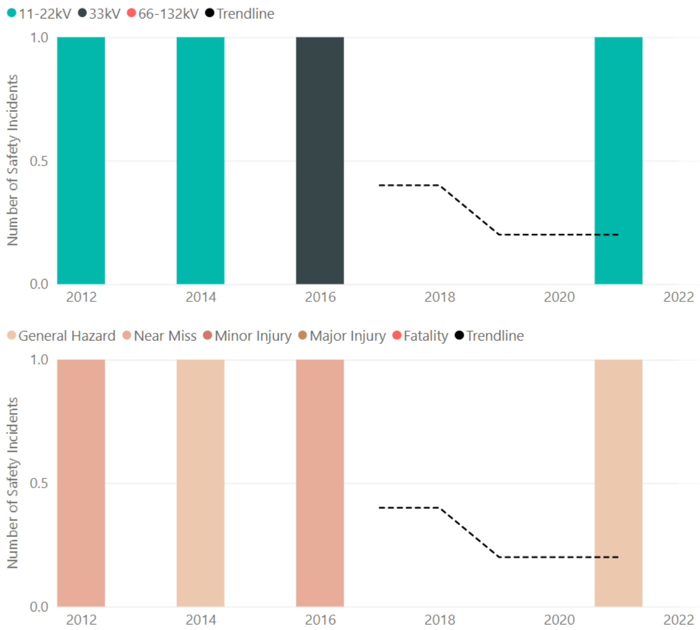
4.2.2. Performance

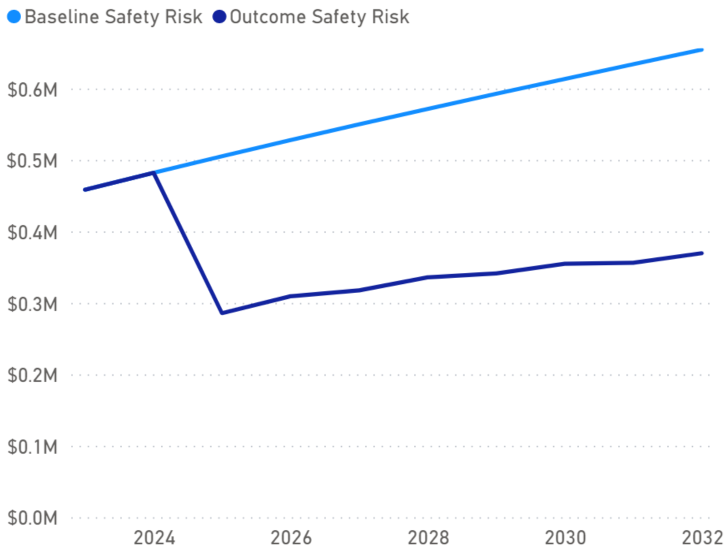
Safety incidents are categorised by severity and include general hazards, near misses, minor injuries, major injuries, and fatalities.

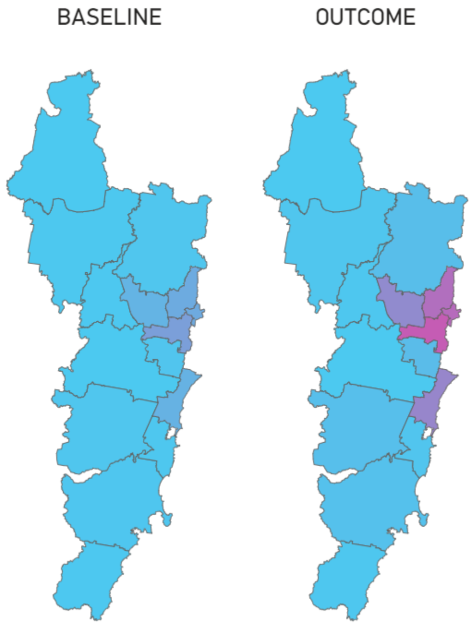
The current asset management strategy is expected to improve safety performance across the fleet of assets as assets at higher risk of failure, which are utilised more often are prioritised for intervention.

The proposed asset strategies are expected to decrease both the frequency of events as well as the total organisational safety risk associated with circuit breakers.

The safety risk concentration indicates that at present areas of the network have a higher normalised safety risk profile, the proposed program will facilitate balancing the normalised safety risk across the network.







Performance Category	Objective	Performance Measure	Asset Type	Current Performance	Performance Target	Status	Trend
Safety	Reduce the number incidents (excluding general hazards)	5-year rolling average of total incidents (excluding general hazards)	11-22kV	0.0	Reduce in line with forecasts	●	—
			33kV	0.0			
			66-132kV	0.0			

4.2.3. Gap

Previous investment strategies were unable to separate out safety as an individual risk. Whilst safety makes up a relatively small portion of the overall risk associated with circuit breakers, it is forecast to reduce (improve) based on the current proposed strategy.

4.2.4. Response

Safety risk will continue to be monitored and risk modelling reviewed as new external factors are identified / occur to improve future forecasts.

4.3 Reliability

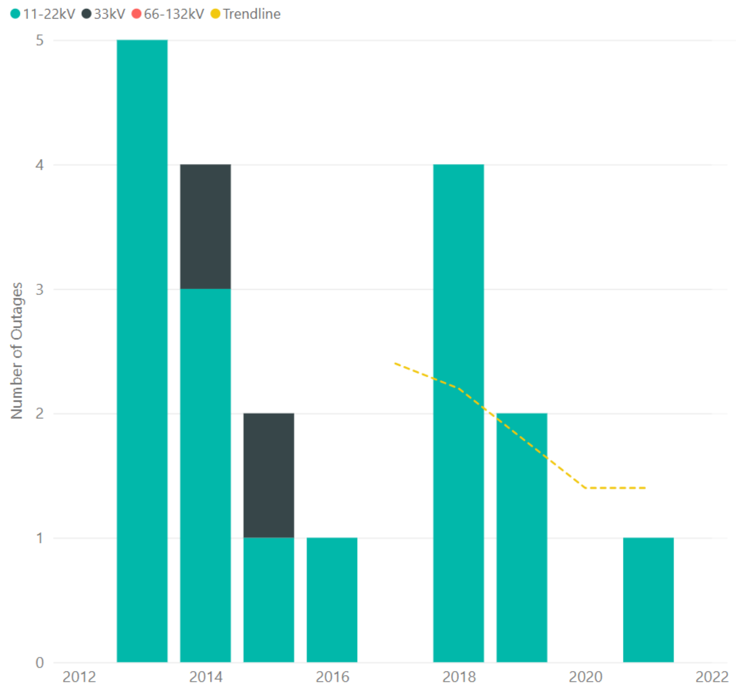
4.3.1. Objective

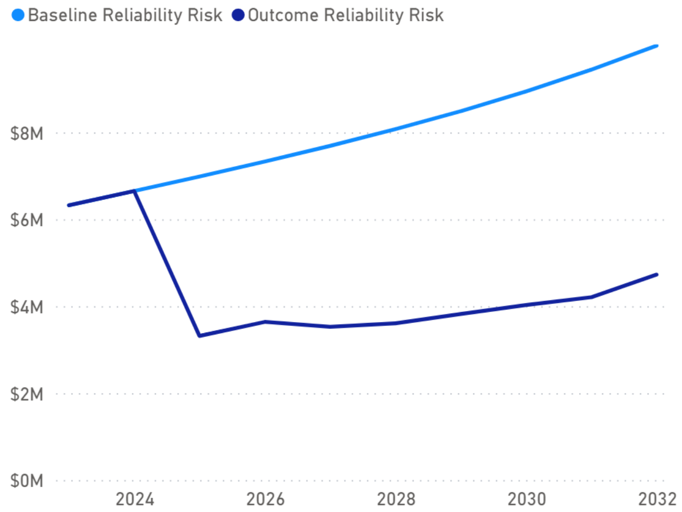
Maintain the level of network reliability risk and number of outages caused by unassisted asset failures associated with circuit breakers.

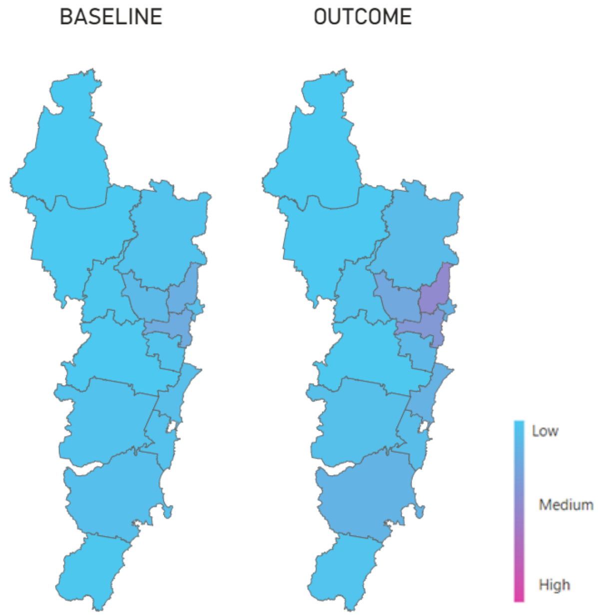
4.3.2. Performance

The number of functional failures associated with circuit breakers has been trending downwards over the past 10 years, the move to an asset level understanding of both probability of failure and reliability risk is expected to create a step change (improvement) in the number of functional failures, however overall reliability risk is expected to remain relatively steady.

The normalised risk concentration across the network is not currently uniform, however is expected to improve over the coming regulatory period.







Performance Category	Objective	Performance Measure	Asset Type	Current Performance	Performance Target	Status	Trend
Reliability	Reduce the number of unplanned outages associated with functional failures	5-year rolling average of unplanned outages	11-22kV	1.4	Reduce in line with forecasts	●	—
			33kV	0.0			
			66-132kV	0.0			

4.3.3. Gap

11kV circuit breakers are the largest contributor to reliability risk, there is a known issue with 11kV bulk oil circuit breakers where they fail to operate under fault conditions causing the upstream protection to operate. The risk associated with these circuit breakers will be addressed through the risk-based intervention strategy.

4.3.4. Response

The current proposed asset management strategy indicates a steady risk profile, with a notable reduction in outcome reliability risk. Continued monitoring of both metrics will be performed to ensure this continues to hold true.

4.4 Network Resilience - TBC

4.4.1. Objective

4.4.2. Performance

4.4.3. Gap

4.4.4. Response

4.5 Bushfire

Not applicable to this asset class.

4.7 Financial

4.7.1. Objective

To align the capital investment in circuit breakers to the forecast spend in the AER REPEX model and to maintain annual maintenance costs.

4.7.2. Performance

The financial risk associated with Circuit Breaker relates to the potential damage to other assets as well as the substation building caused by the functional failure of as well as the reactive costs associated with the replacement of these assets.

Performance Category	Objective	Performance Measure	Asset Type	Current Performance	Performance Target	Status	Trend
Financial	Maintain annual maintenance costs for the asset class	10-year rolling average of maintenance costs	All	$0.4M	Maintain	●	—

4.7.3. Gap

The proposed capital investment in circuit breakers is much greater than the forecast spend in the AER REPEX model, this is due to the exclusion of 11-22kV circuit breakers within the latest REPEX model due to a lack of suitable RIN data for the replacement costs. The proposed capital investment also includes the replacement of switchboard surrounds as well as the circuit breaker which is not considered in the REPEX model.

4.7.4. Response

This variation is to be continued to be monitored and improvements in RIN data explored.

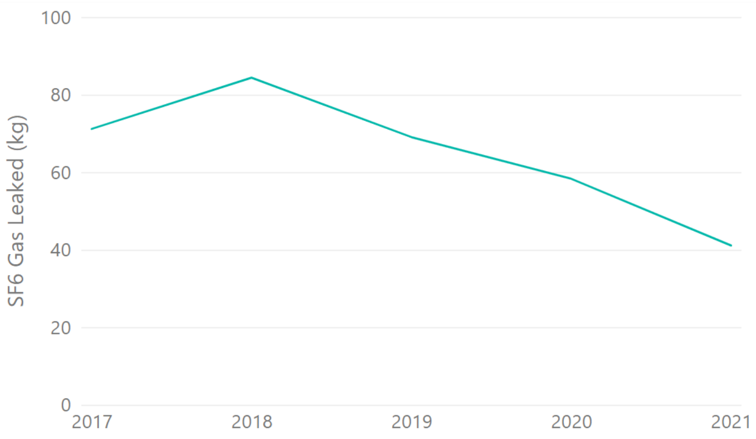
4.8 Environmental

4.8.1. Objective

To reduce environmentally harmful emissions, particularly SF6 gas, to support the company's Net Zero Emissions and Sustainability Linked Loan targets.

4.8.2. Performance

Endeavour Energy records an average of 65kg of SF6 lost due to leakage per annum which represents 0.2% of the total mass of SF6 gas within the circuit breaker asset population. Current data shows a decline in total leakage over the last 4 years, however, the metrics for monitoring both SF6 holdings and leaks are still being developed.



Performance Category	Objective	Performance Measure	Asset Type	Current Performance	Performance Target	Status	Trend
Environmental	Reduce the leakage of SF6 gas to atmosphere to support the company's Net Zero Emissions and Sustainability Linked Loan targets	SF6 leakage in CB's (kg) over the last five years	SF6 CBs only	65kg	Maintain	●	—
		% of average annual leaked SF6 gas (over 5 years) to the total mass of SF6 gas in CB population		0.2%	Reduce	●	—

4.8.3. Gap

Currently, the financial impacts of SF6 gas leaks from circuit breakers are captured under the maintenance costs for the asset class, however, the environmental impact from the leakage of SF6 gas into the atmosphere has been excluded from the cost benefit analysis due to a lack of agreement on the value of SF6 gas emissions across the Australian electricity industry.

Data quality improvements in the capture of SF6 leakage from assets have been identified and are currently in the processes of being improved. Re-baselining of SF6 trends may be required in the future.

4.8.4. Response

Metrics for the monitoring of SF6 holdings, leakage and disposal are currently being created to support the organisations objectives associated with environmental management and once a cost of consequence associated with SF6 gas leaks is implemented, this data will be used in future cost benefit analysis of this asset class.

5. Asset Lifecycle

This section discusses circuit breakers throughout the asset lifecycle and brings to light key factors that currently (or may) impact the asset class performance.

5.1 Acquisition

The types of circuit breakers installed on the network has varied over time with changing technology and insulating mediums. For 11kV and 22kV circuit breakers, bulk oil circuit breakers were largely installed in the 1960's through to the 1980's, SF6 circuit breakers were largely installed from 1980 to the early 1990's and vacuum circuit breakers have largely been installed from 1989 onward.

For 33kV, 66kV and 132kV circuit breakers, bulk oil and small oil circuit breakers were installed in the 1960's onwards with the transition to SF6 as an insulating medium occurring throughout the 1980's. The 1990's saw the introduction of 33kV vacuum circuit breakers on the network and remains the suitable insulating medium for 33kV circuit breakers. The most suitable insulating medium for 66kV and 132kV circuit breakers remains to be SF6.

The continued monitoring of the asset class will allow further refinement of technology mix and network configurations options being implemented.

The current technical criteria for this asset class are defined in Equipment Technical Specifications (ETS) as listed in Section 8.1. Asset types have largely been defined based on the technology type, however as performance data indicated the current asset types will continue to be further subdivided.

5.2 Operations

Circuit breakers are designed to break both normal operating current as well as fault current. The continuous current rating of a circuit breaker is determined by the voltage level, equipment type (feeder bay, transformer bay, bus section) and ultimate loading levels of a transmission or zone substation

SDI 501 *Subtransmission Network and Zone Substation Configuration* outlines both standard operating current ratings and short circuit fault levels.

At present, there is a known issue with a subset of 11kV vacuum circuit breakers where a leak in the vacuum tube can result in phase to ground fault during switching operations with a subsequent arc flash presenting a safety risk to the operator. Newer style switchboards address this safety risk through arc fault containment and proposed control measures for older switchboards include the use of remote-control motorised racking systems and arc flash protection devices.

5.3 Maintenance

An overview of the current maintenance activities being performed on circuit breakers are summarised below. These maintenance activities result in the current asset performance (e.g. risk and number of unassisted / conditional asset failures). The shift to an asset level risk-based replacement strategy is expected to provide a step change (improvement) in risk during the FY23-FY29 regulatory period, however the underlying risk will continue based on the following maintenance strategy.

The average annual maintenance costs for the fleet of circuit breakers over the last 10 years is $396,471.

5.3.1. Inspections & Preventative Maintenance

Generally, maintenance on circuit breakers include:

- Inspection, where visual inspection tasks and operational checks are completed
- Exercise, where circuit breakers that have not been operated in the last 12 months are operated to prevent degradation of contacts.
- Minor maintenance
- Major maintenance

The schedules of maintenance for circuit breakers are outlined in SMI 200 *HV circuit breakers* and vary across the population based on voltage, insulating medium, manufacturer and type. The maintenance intervals based on voltage, insulating medium, manufacturer and type can be found in SMI 100 *Minimum requirements for maintenance of transmission and zone substation equipment.*

5.3.2. Essential Spares

The requirement for an essential spare's strategy is governed by the criticality of the equipment's function in the network and is dependent on the lead time for acquisition.

As circuit breakers are deemed critical to the operation of the network, an essential spares strategy has been developed to ensure that a supply of complete circuit breaker assemblies as well as major and minor components are readily available for use in fault and emergencies.

The number and type of essential spares carried will be probabilistically assessed for each of the major categories of assets based on their distribution and experience of their:

- failure rates;
- modes of failure;
- population;
- criticality in the network;
- lead time for the spares; and
- cost of the spares.

Based on the above, the minimum acceptable service level for spares holdings will be such that a minimum 99% service level can be achieved for each of the major asset classes.

Essential spares are to be suitably stored in readily accessible locations and maintained in good working order so that they can be easily identified and ready for service when required.

Endeavour Energy's procurement and logistics section is responsible for the on-going sourcing strategy of circuit breakers including its supply chain security.

5.4 Disposal

The disposal of retired circuit breakers is to be undertaken in accordance with Endeavour Energy's environmental management standards, EMS 0007 *Waste Management* and EMS 0017 *Oil Management.* Circuit breakers of concern include oil-filled circuit breakers as well as SF6 filled circuit breakers due to the negative effect that the insulating mediums can have on the environment if not disposed of properly.

6. Intervention Options

A range of options have been considered as possible intervention options to address the risk presented by circuit breakers. These options are initially considered as an asset type / class level to determine if they are technical feasible and/or practical. Intervention options deemed to be a viable option are then considered at an asset level to determine the most appropriate option for each individual asset.

Intervention Type	Option	Assessment of effectiveness	Credibility
Non-Network Based	-	Due to the substantial load that each circuit breaker carries on a continual basis and the asset's primary functionality being to protect / isolate / switch the network, there are no credible non-network solutions which could replace their functionality.	Not A Feasible Solution
Condition Based	Additional maintenance to extend the life of the existing asset	Maintenance procedures are able to ensure an otherwise sound CB asset reaches its full life potential. Unavailability of replacement parts for aged assets limits the extent to which maintenance can extend the life of a circuit breaker.	Not A Feasible Solution
Risk Based	Reduce the load on the asset through network reconfiguration, network automation or demand management	The risk of failure is generally independent of load. A minor reduction in the consequences of failure could be achieved by transferring load from any of the CBs but there is little capacity to do this in the surrounding network at any scale. The circuit breakers are integral to the supply to their substations which are required to carry load for the foreseeable future. Further, there are no practicable non-network solutions for replacing a zone or transmission substation. Disconnecting and bridging out a CB will reduce the discrimination of protection systems and increase the reliability impact on customers of faults that occur in that part of the network.	Not A Feasible Solution
	Implementing operational controls such as limiting	These controls are in place to limit the safety risks presented by this equipment to workers, but the principal risk that drives the need for intervention is reliability, which cannot be affected by practicable controls.	Controls only safety risk for workers

Intervention Type	Option	Assessment of effectiveness	Credibility
Non-Network Based	-	Due to the substantial load that each circuit breaker carries on a continual basis and the asset's primary functionality being to protect / isolate / switch the network, there are no credible non-network solutions which could replace their functionality.	Not A Feasible Solution
	access, remote switching protocols etc		

6.1 Non-Network Based Interventions

No non-network based interventions have been identified to replace the primary function of this asset class.

6.2 Condition Based Interventions

The inspections and preventative maintenance programs outlined in 5.3 Asset Maintenance results in the following condition-based repairs, replacements, and defects on circuit breakers. The objective of the condition-based maintenance is to identify functional asset failures prior to them occurring, however as close as possible to the assets technical / economic end of life.

Defects are directly linked to an asset's failure mode(s) and aim to identify issues with the defect that will result in it being unable to perform its primary intended function. Defects are currently prioritised based on a qualitative assessment of the likelihood the defect will result in a functional failure.

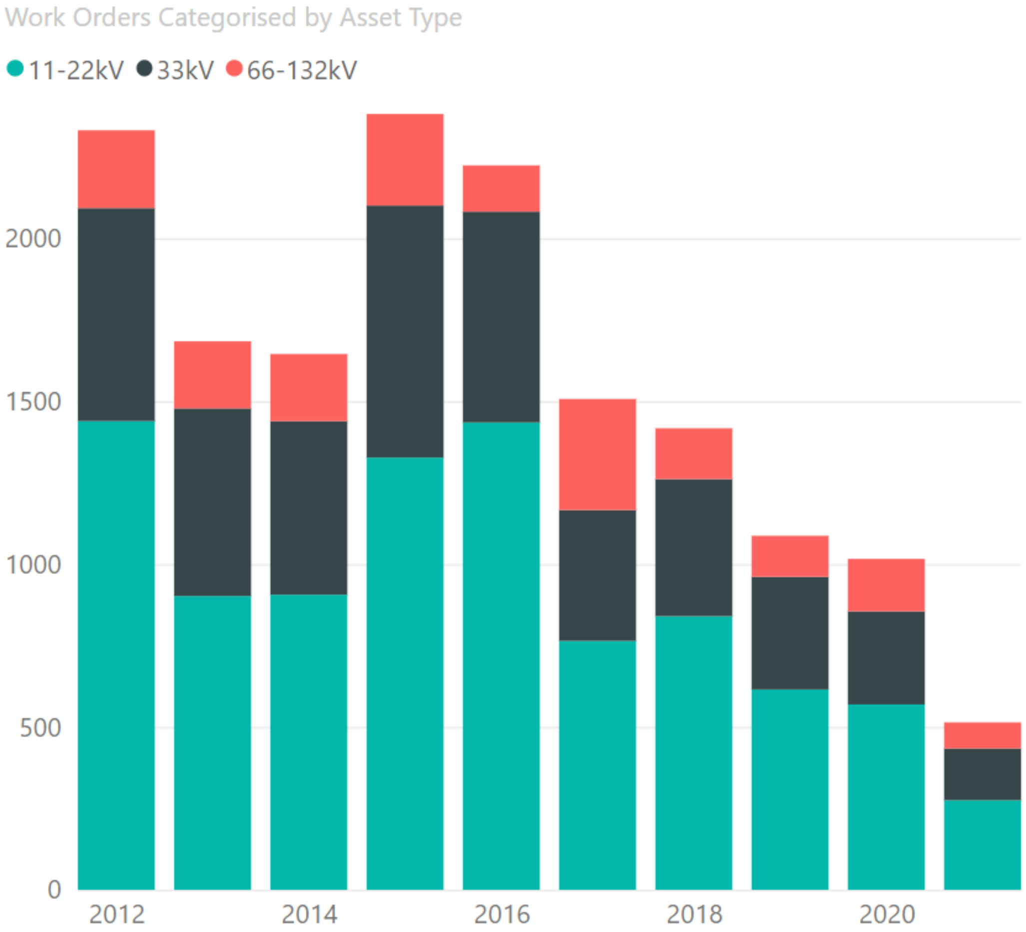
Endeavour Energy determines what constitutes a defect based on Failure Modes Effects and Criticality Analysis (FMECA). FMECA is an analytical process that is derived from an assessment of an asset's ability to sustain technical function and purpose and relies on information relating to failure modes, their probability and consequences of failure. FMECA establishes a condition-based approach to asset maintenance that enables a risk-based determination of the maintenance requirements for assets.

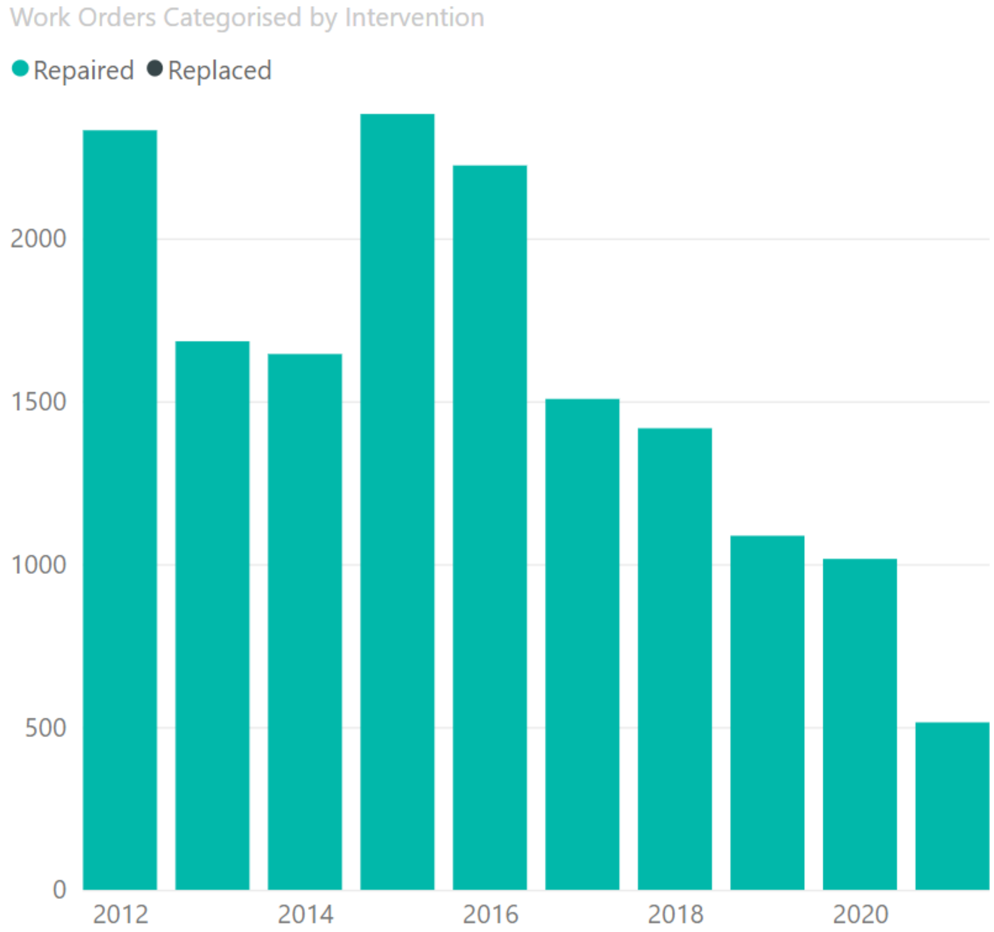
SMI 124 *Maintenance data entry and defect prioritisation* and SMI 200 *HV circuit breakers* provide further detail on what is to be recorded as a defect, the required actions, and the corresponding priority for each failure mode, the table below provides an overview of applicable defects associated with circuit breakers.

Defects	Repair / Replacement	Standard job description
1FAULT	-	For storms and major events or can be used when another standard job is not suitable
1TRCBM	Repair	Transmission Defect - CBM

Defects	Repair / Replacement	Standard job description
1TRDFE	Repair	Transmission Defect – F&E
CBRMAJ	Repair	CB Repair (Major)
CBRMIN	Repair	CB Repair (Minor)
HVSWZS	Repair	HV Test – Switchgear (TS & ZS)
PCFEAS	Repair	P&C – F&E, Assist Trans Subs
PCINVT	Repair	P&C – Protection Investigation
SF6LOW	Repair	SF6 Low
TSFEAS	Repair	Trans Subs – F&E, Assist P&C
TSINVT	Repair	Trans Subs – Test & Investigation

At present, 11kV circuit breakers are responsible for the majority of defects within the circuit breaker asset class, however, the overall volume has been reducing (improving) over the past five years, indicating an improvement in the condition of the asset base and therefore a reduction in the likelihood of failure. The condition-based interventions are largely asset repairs rather than replacements.





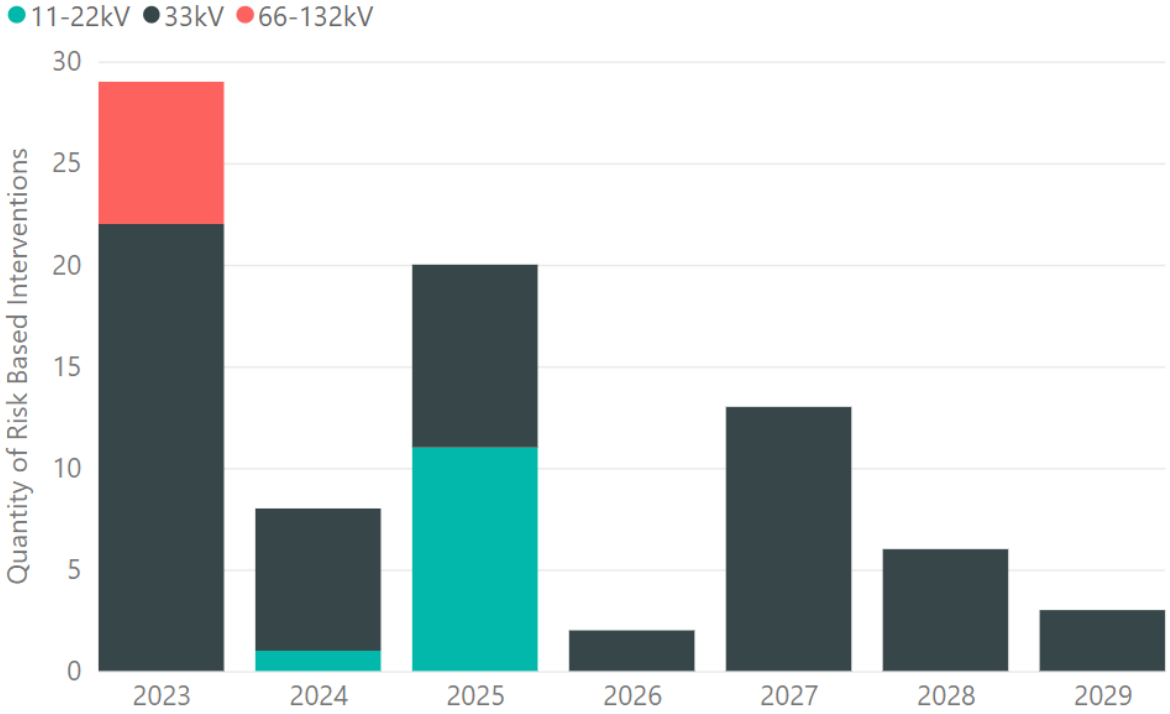
6.3 Risk Based Interventions

Risked based intervention options considered as possible feasible intervention options have been further considered to address the risk presented by circuit breakers at the asset level. The customer benefit achieved by the proposed intervention option is compared with the cost of the proposed intervention(s) to determine if the option is financially viable and in the customer's interest. This approach generates a cost to benefit ratio / NPV for every asset and intervention option being considered.

The forecast risk projections (e.g. safety, reliability, resilience, bushfire etc) throughout this document are based on the current optimal investment profiles proposed in the Case for Investments (CFI's) associated with this asset class (detailed below).

The intervention strategy for circuit breakers includes the complete replacement of the circuit breaker in a planned proactive manner to allow for the retirement of the existing circuit breaker.

The following volume of forecasts / breakdown between options are based on the results of the CFI's associated with this asset class.

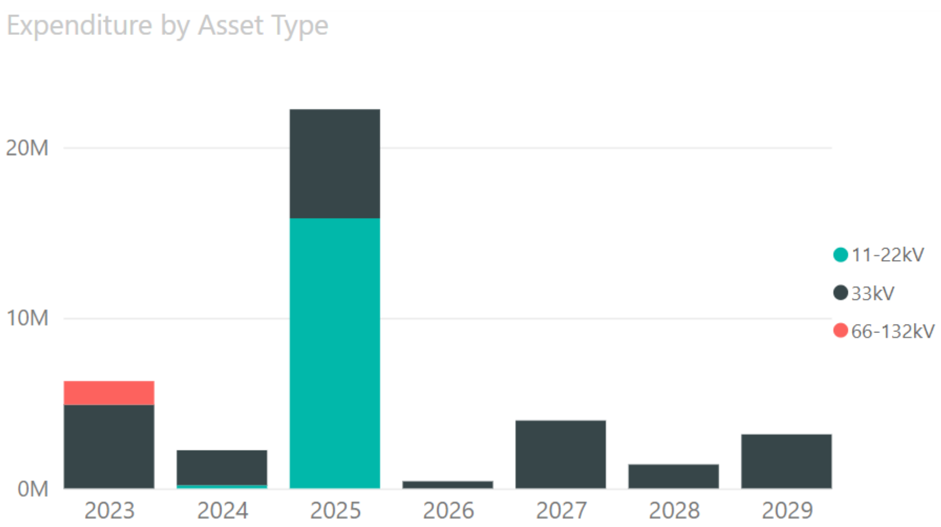


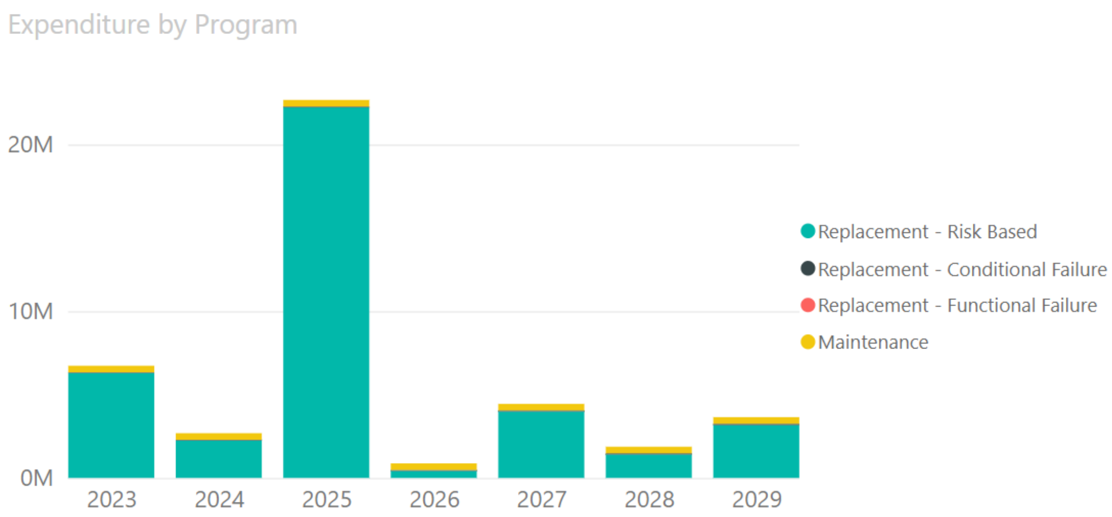
7. Forecasts

7.1 Cost

The risked based replacement program has identified assets within this asset class that are currently justified for a risk-based asset intervention over the upcoming regulatory period. The proposed investment profile peaks in FY25 as indicated in the expenditure profiles, this peak is expected to be spread across the regulatory period due to additional restraints, such as, labour and outage availability.

Over the next 7 years, inspection and maintenance spend is expected to remain stable.



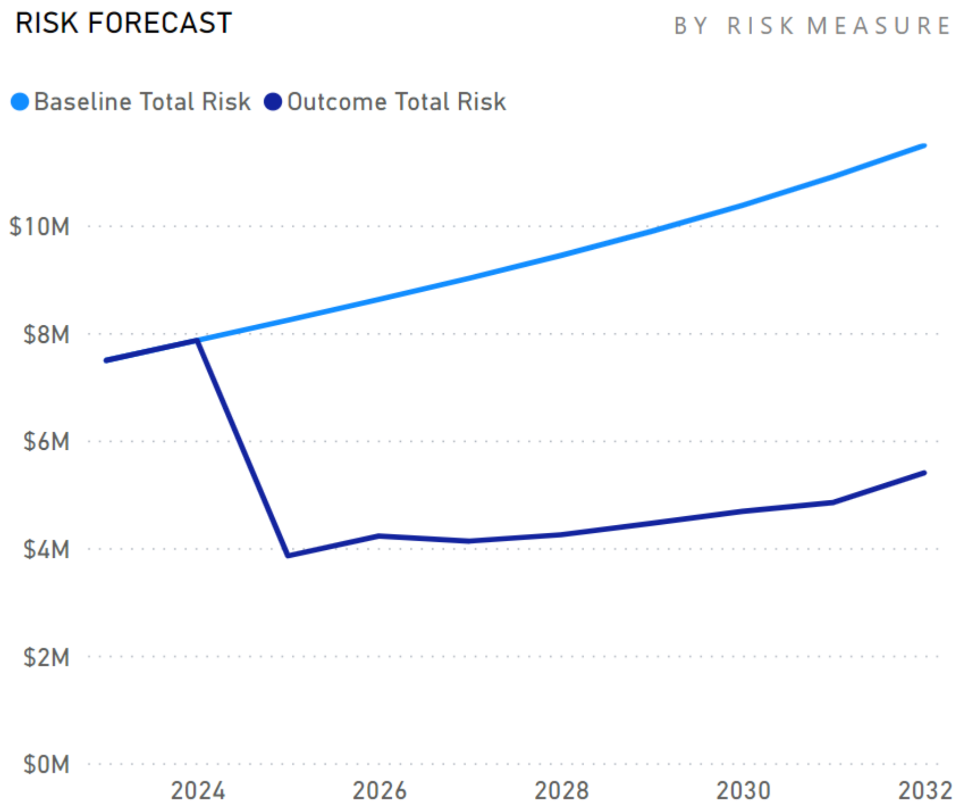


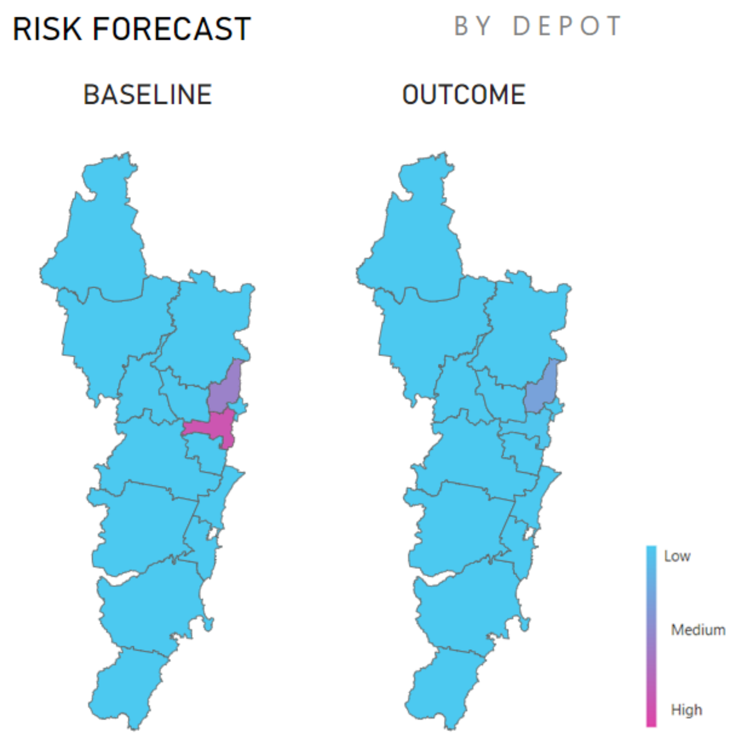
7.3 Risk

Network risk associated with HV circuit breakers has been calculated as per the current value framework. The total risk in this asset class is made up from Reliability (81%), Financial (18%) and Safety (1%).

The baseline risk (no intervention) associated with this asset class is projected to increase to $12 million if no action is taken. The outcome risk based on the proposed intervention profile is however projected to remain steady at $5 million over the following eight year period.

It can also be seen that the total risk will become much more uniform across the network with the majority of the investment focused in higher density residential / CBD areas, as the risk is predominantly driven by network reliability.





8. Asset Management Systems

This section identifies the strategies, practices and guidelines supporting the management of this asset class.

The relationship between this document and the other artefacts within Endeavour Energy's asset management system is illustrated below:

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A detailed description of Endeavour Energy's asset management system and its constituent parts is available in the Asset Management System Manual and the Asset Management System Guidelines.

8.1 Standards, Guidelines & Policies

Endeavour Energy's asset management practises are governed and guided by numerous legislative requirements, guidelines, and industry best practises throughout Australia and Internationally. Endeavour Energy's manuals, procedures and workplace policies are all underpinned by these key documents as documented in 'GQY 1190 Policy and Procedure Framework' and demonstrated in the adjacent figure. Legislation, regulations, and high-level Australian Standards applicable to HV network operations are detailed in the Endeavour Energy Asset Management System.

Endeavour Energy has developed the following documentation to specifically guide the life-cycle management of circuit breakers:

Company Policies

9.1.6	Approved Materials List
9.1.7	Commissioning network Electrical Assets
9.1.9	Network Technical Compliance
9.2.1	Network Planning
9.2.2	Network Protection
9.2.5	Network Asset Design
9.7.1	Network Asset Construction
9.8.3	Network Operations
9.9.1	Network Asset Maintenance
9.9.2	Essential Spares

Approved Materials Lists & Specifications

ETS 0003	11kV, 22kV and 33kV indoor metal-enclosed switchgear
ETS 0010	Mineral insulating oil
ETS 0022	33kV, 66kV and 132kV outdoor dead tank circuit breakers
ETS 0029	Regenerated mineral insulating oil
ETS 0031	11kV vacuum CV truck retrofits for bulk oil CBs
ETS 0032	Natural ester insulating oil

Design Instructions

SDI 501	Substation network and zone substation configuration
SDI 505	Minimum design & construction requirements for transmission & zone substations & switching stations
SDI 545	Acceptable purity limits for SF6 gas
SDI 547	Alarm and tripping requirements in SF6 and dry air equipment

Construction & Commissioning Standards

SDI 120	Testing and commissioning for distribution systems
SDI 535	Site testing and pre-commissioning

Maintenance & Operations Standards

SMI 100	Minimum requirements for maintenance of transmission and zone substation equipment
SMI 102	Testing of in-service insulating oil
SMI 119	Transmission and zone substation data asset structure and nameplate details
SMI 121	Storage and handling of insulating oil
SMI 122	Use and handling of sulphur-hexafluoride (SF6)
SMI 124	Maintenance data entry and defect prioritisation
SMI 200	HV circuit breakers
SMI 210	33kV – 132kV indoor air and gas insulated switchgear
SMI 213	11/22kV Indoor Switchgear

8.2 Asset Management Tools

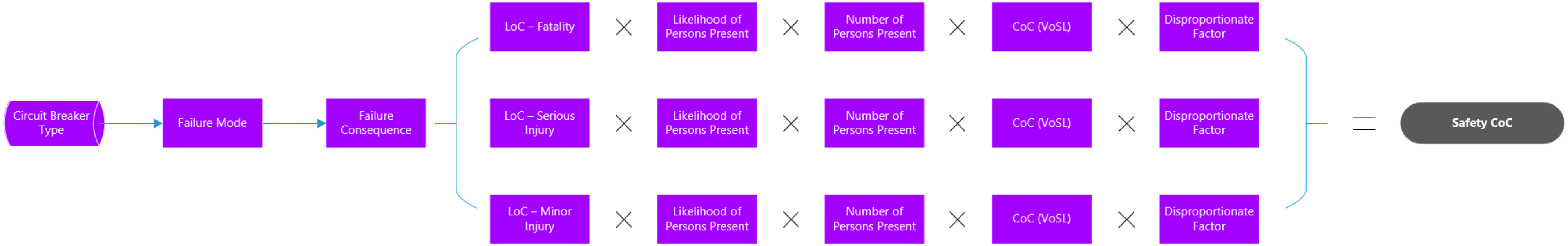
Endeavour Energy use numerous integrated data-base and geographical information system related tools to aid in the management of circuit breaker assets.

Key tools used for the management of circuit breakers include:

Tools	Current Purpose	Future Purpose
Ellipse Database	Used for historical (2010-2021) asset nameplate details, routine maintenance scheduling, defect workorder recording and management	Superseded by SAP
SAP	Used for recent (2021-Current) asset nameplate details, routine maintenance scheduling, defect workorder recording and management	To be used as the primary data source for: • Asset characteristics • Financials • Safety – safety incidents are to be categorised by asset class, asset type, and severity • Bushfire – bushfire incidents are to be categorised by asset class, asset type, and severity • Environmental – environmental incidents such as SF6 gas leaks are to be captured and categorised by asset class, asset type, and severity
ADMS	Not currently used	To be used as the primary data source for: • Reliability – reliability incidents are to be categorised by asset class, asset type, and include SAIDI and SAIFI contributions. • Resilience – Benefits from network automation to be quantified • Utilisation – switching events are to be categorised by asset class and asset type.
SwitchIt	Used to determined switch utilisation in terms of switching frequency	Superseded by ADMS
OMS	Used for historic (2012-2021) asset related reliability incidents	Superseded by ADMS
FireStart	Used for historic (2005-2021) asset related firestart incidents	Superseded by SAP
MySafe	Used for historic (2012-2021) asset related safety incidents categorised by severity	Superseded by SAP

Appendix A – Cost of Consequence

Safety



Parameter	Value	Description/justification	Source/assumptions
Value of a fatality	$5,100,000	Value of statistical life (VoSL)	EE Copperleaf Value Model – based on Office of Best Practice Regulation published values
Value of a serious injury	$2,249,000	44.1% of VoSL	GNV1119
CB failure results in injury - LoC	2%	Likelihood of person being in the vicinity of the CB	Estimate based on generalised visit to substations by maintenance and other workers
	0 - 25%	Likelihood of causing a fatality if someone is present: 0% for SF6 or vacuum CB 10% for oil CB in the switchyard 25% for oil CB in control building	Estimate based on inspections of the aftermath of asset failures in switchyards and control buildings
	0 – 75%	Likelihood of causing a serious injury someone is present 0% for SF6 or vacuum CB 30% for oil CB in the switchyard 75% for oil CB in control building	Estimate based on inspections of the aftermath of asset failures in switchyards and control buildings
	10%	Likelihood of causing a minor injury someone is present 10% for SF6 or vacuum CB	Estimate based on inspections of the aftermath of asset failures in switchyards and control buildings
		Number of persons likely to be present is 2, out of a population of 50 likely to be exposed	Estimate based on usual size of work teams and the population of workers frequenting substations

Parameter	Value	Description/justification	Source/assumptions
Safety disproportionate factor	3	Reflects the weight placed on safety by society	The minimum value from GNV1119 based on the low likelihood of fatality

Reliability

LoC – Loss of Supply to Customers × Load Impacted (MW) × Load Factor × LGA Average VCR ($/MWh) × Duration of Interruption (hrs) = **Reliability CoC**

Parameter	Value	Description/justification	Source/assumptions
Loss of supply to customers - LoC	1% generally 33 - 100% for specific cases	1% likelihood of loss of load when N-1 supply security is available The likelihood of loss of load depends on the position of the CB within the substation, the number of busbar sections and the presence of bus-section circuit breakers. Varies from 33% loss of load where three automatically bus-sections are available to 100% where only one is available	RisCAT - 1% likelihood the alternate supply path will not be available due to maintenance, or failure. Ellipse data and count of bus-section CBs at each voltage in each substation in FME to resolve the likely level of supply security for each CB and the location of switching to automatically restore supply after a CB failure. Verified by review of specific sites in SOPS
Load impacted	Specific to each substation/switching station	The summer maximum demand of the substation at 50% probability of exceedance	2021 Summer Maximum Demand planning report
Load factor	70%	Load assumed to be lost is 70% of the summer maximum demand value for the supplied substation(s)	Source – studies of network faults by Protection Manager.
VCR	Specific to each substation/switching station	Value of customer reliability for an occasional short-term outage	Specific values for each substation/switching station calculated by Network Planning based on values published by the AER
Duration of interruption	4 hours	4 hours assumed interruption until alternate arrangements are made for supply through switching the network	A generalised value based on a range of outages of transmission assets. Assumes off-loading to reinstate supply through a

Parameter	Value	Description/justification	Source/assumptions
			combination of SCADA and manual switching of disconnectors on site and distribution switches in the field as appropriate

Financial

LoC – General × CoC – General + LoC – Damage to Buildings × CoC – Damage to Buildings + Reactive Replacement Costs = **Financial CoC**

Parameter	Value	Description/justification	Source/assumptions
Financial general - CoC	$20,000	Switching to restore supply/supply security, clean-up, any temporary diversion works, investigation, media management costs	Estimate, based on typical clean-up and investigation costs
Financial general - LoC	100%	Likelihood of general financial risks being realised on failure	Will always be realised to an average extent.
Financial – damage to buildings – CoC	$700,000	Recovery costs for an oil CB failure in a control building – 100% LoC for oil switchboard 0% LoC for SF_6 and Vacuum	Estimate based on experience of past oil switchboard failures
	$300,000	Provision of load support by temporary switchboard 10% LoC for oil switchboard 0% LoC for SF_6 and Vacuum	Estimate based on experience of past oil switchboard failures
	$50,000	Provision of load support by generators 25% LoC for oil switchboard 0% LoC for SF_6 and Vacuum	Estimate based on experience of past oil switchboard failures

Parameter	Value	Description/justification	Source/assumptions
	$100,000	Recovery costs for an oil CB failure in a transmission substation chamber – 100% LoC for oil switchboard 0% LoC for SF_6 and Vacuum	Estimate based on experience of past oil switchboard failures
	$150,000	Recovery costs for damage to adjacent bay equipment for outdoor CB 33% LoC for oil CB 0% LoC for SF_6 and Vacuum	Estimate based on experience of past oil switchboard failures
Reactive replacement costs	Varies	Reactive replacement costs generally equal planned replacement costs except that whole switchboard replacement will be required for all oil switchboards and older SF_6 and vacuum switchboards without current standard CB and busbar chamber barriers and arc-fault ducting and venting	Estimate based on experience of past oil switchboard failures

Appendix B – Weibull Parameters

Parameter	Value	Description/justification	Source/assumptions
α (Alpha)	Varies for the range of CB types. Refer table below	The “scale” parameter used for calculating probability of failure. This, along with the shift variable γ sets the mean time to failure for the asset	Failure data is sparse and not helpful. Estimated to give a reasonable looking MTTF, which range from 46 years for an 11kV SF_6 switchboard comprised of 12 CBs to 96 years for an individual 11kV bulk oil CB These values provide reasonable correlation with the actual very low annual failure rates being experienced and address the difference in probabilities of failure for individual assets which are generally independent of each other and the older style switchboards where the failure of any one CB in the switchboard will cause the end of life for the entire switchboard. The PoF of the switchboard in these cases is an aggregation of the PoF of each CB plus each section of busbar and is 1 – the probability of each element of the switchboard surviving the year. Refer table below.
β (Beta)	Various for the range of CB types. Refer table below	The “shape” parameter used for calculating probability of failure function. Sets the shape of the distribution of failure ages in a population of assets.	The generalised wear-out function shape for a normal distribution is 3.6. Adjusted values have been applied to switchboards to match the combined failure probabilities of the constituent CBs and busbars. Refer table below.

Parameter	Value	Description/justification	Source/assumptions
γ (Gamma)	Various for the range of CB types. Refer table below	The “shift” parameter which gives a failure-free period at the start of the asset’s life.	Estimated values applied to reflect the very low number of functional failures recorded for the fleet of assets to date, then a forecast an increase in failures as the assets become aged and wear out. Refurbished switchboards (with CB truck replacements) are represented in the model with the same Weibull function but a reduced shift parameter to reflect the conditional age of the switchboard after refurbishment. $Shift_{refurbished} = 30_{(initial)} - 50_{(years\ at\ refub)} = -20$ years

CB asset type	Weibull shape parameter	Weibull scale parameter (yr)	Weibull shift parameter (yr)	MTTF (yr)	Comments
11-22kVBULKOIL_IS_1	3.8	51.6	25	72	emulates the combined PDF of an 11kV oil switchboard with 1 BS and 4 CBs
11-22kVBULKOIL_IS_2	3.9	38.8	25	60	emulates the combined PDF of an 11kV oil switchboard with 2 BS and 13 CBs
11-22kVBULKOIL_IS_3	3.9	34	25	56	emulates the combined PDF of an 11kV oil switchboard with 3 BS and 21 CBs
11-22kVBULKOIL_O	3.6	75	28	96	
11-22kVSF6_IS	3.6	70	15	78	
11-22kVSF6_O	3.6	70	15	78	
11-22kVSMALLOIL_O	3.6	60	10	64	
11-22kVVACUUM_IS	3.6	65	10	69	
11-22kVVACUUM_IST	3.6	80	-20	52	Weibull for old air-insulated busbars (3.6/80/30) shifted for 50 years nominal age at installation of trucks
11-22kVVACUUM_O	3.6	60	10	64	
132-66kVSF6_IS	3.6	55	15	65	
132-66kVSF6_O	3.6	55	15	65	
132-66kVSMALLOIL_O	3.6	55	15	65	
132-66kVVACUUM_O	3.6	55	6	56	
33kVBULKOIL_IC	3.6	60	25	79	
33kVBULKOIL_IS_2	3.6	41	25	62	emulates the combined PDF of an 33kV Boil switchboard with 2 BS and 6 CBs
33kVBULKOIL_O	3.6	60	25	79	
33kVSF6_IC	3.6	60	10	64	
33kVSF6_IS	3.6	60	10	64	
33kVSF6_O	3.6	60	10	64	
33kVSMALLOIL_IS_2	3.6	38	15	49	emulates the combined PDF of an 33kV Soil switchboard with 2 BS and 5 CBs
33kVSMALLOIL_O	3.6	50	15	60	
33kVVACUUM_IC	3.6	60	10	64	
33kVVACUUM_IS	3.6	60	10	64	
33kVVACUUM_O	3.6	60	10	64	
AuxiliarybusbarCB_IA	3.6	60	10	64	
InternalcapacitorCB_IA	3.6	60	10	64	
SubstationLBS-REC_O	3.6	60	10	64	
11-22kVSF6_IS_2	3.6	34.5	15	46	emulates the combined PDF of an 11kV SF6 switchboard with 2 BS and 12 CBs
33kVSF6_IS_2	3.6	38	10	44	emulates the combined PDF of a 33kV SF6 switchboard with 2 BS and 5 CBs
132-66kVSF6_IS_2	3.6	38	10	44	use 33kV SB Weibull for starters

Appendix C – Additional Asset Information

Asset risks

Sub-transmission circuit breakers have a range of failure modes. *Conditional* failures generally have no immediate consequences but indicate impending *functional* failure, which will impede the circuit breaker from carrying out its required function.

Conditional failures may be classed as "defects" and include failing to pass maintenance tests of:

- Speed of opening and closing;
- Insulation resistance;
- Contact resistance; or
- Bushing dielectric loss-angle.

They also include:

- Corrosion of casings; and
- Leakage of insulating oil or SF_6 gas; and
- Discharge across bushings.

Functional failures include:

- Failure to operate when required;
- Failure to clear a fault, which may lead to the destructive failure of the circuit breaker;
- Failure of insulation, leading the destructive failure of the circuit breaker.

Functional failures result in consequences which may include:

- Loss of supply to customers, depending on the arrangement of the host substation and the where the breaker fits in the topology of the substation;
- A safety risk to persons present near the circuit breaker at the time of the incident;
- A financial impact of switching around the failed asset, cleaning up damage, investigating the incident and replacing equipment in adjacent bays damaged by the failure;
- Environmental impacts, particularly due to the loss of SF_6 gas; and

- Reactive capital costs – the cost of replacing the failed circuit breaker or switchboard in a reactive manner.

There are also conditional failures which have an economic value and increase the service cost of the asset beyond average values. These are captured under the umbrella of *maintenance* costs and include:

- Additional maintenance works to address oil/SF_6 gas leaks and mechanical failures; and
- The environmental impact of leakage of SF_6 gas.

The consequences of failure vary significantly from circuit breaker to circuit breaker depending largely upon the network topology of their location and hence the reliability impact of the failure. The sensitivity to network topology is due to the fact that on failure, the failed CB is isolated from the rest of the network by the surrounding circuit breakers opening. Depending on the network topology, the reliability impact of this varies from nil to the loss of supply from an entire zone substation for an extended period whilst the network is reconfigured by manual switching of disconnectors on site and/or transferring customer load to other sources of supply.

Overall, however, reliability is the principal risk which drives proactive circuit breaker retirement and replacement.

Response to conditional failures (Failure modes and effects)

Conditional failures of circuit breakers are relatively common and the response varies depending on the type of failure and the type, location and age of the circuit breaker involved. The table below summarises the responses to a typical range of conditional failures

Conditional failure/defect	Typical cause	Comments	Typical response
Slow opening	• Issues with lubrication • Wear of mechanism • Trip coil burn out	In some instances it can be corrected through maintenance activity but if occurring with other similar mechanical failures – may indicate wear-out phase for the CB Can deteriorate to an explosive functional failure in all types of CBs	• Maintain, or • Replace parts, or • Consider replacement of CB
Slow closing	• Issues with lubrication • Control relay failure • Wear of mechanism	Is also a Functional failure if it stops the CB carrying out its switching function. In some instances can be corrected through maintenance. IDEC relay failure is known issue which is addressed by replacement of the relay by a different type. Refer Technical Bulletin TB 0283. Mechanism wear can in some cases be addressed through replacement parts (eg 66kV SF_6 CBs in the ELG switchboards at West Pennant Hills and Hazelbrook zone substations) but in other cases where parts are no longer available – may indicate end of life of the CB	• Maintain, or • Replace parts, or • Consider replacement of CB

Conditional failure/defect	Typical cause	Comments	Typical response
Low insulation resistance	Break down of insulation, usually due to moisture ingress	Usually signals the end of the assets life Can deteriorate to explosive functional failure	• Consider replacement of CB
High contact resistance	Wear of contacts due to use, and or wear of arc-quenching components	Dressing contacts during maintenance Replacing contacts where parts are available May indicate wear out of the CB Can lead to overheating of the contacts under heavy load and result in explosive failure in oil CBs	• Maintain, or • Replace parts, or • Consider for replacement of CB
Bushing dielectric loss-angle	Break down of insulation, usually due to moisture ingress	Replacement bushings are available for outdoor standalone CB such as Westinghouse GC/GCN, which tend to suffer from this failure mode For other types of CBs and in particular insulation in switchboards, this may signal the end of life of the asset. Can deteriorate to explosive failure of the bushing. This may be a repairable failure for standalone outdoor CBs but an end of life event for a switchboard.	• Replace bushing; or • Consider for replacement
Discharge across insulation	Pollution on insulation surface Breakdown due to deterioration with age or manufacturing defects	Cleaning during maintenance may have an effect Replacement insulators/bushings are available for some newer CBs Otherwise it may indicate end of life. Can deteriorate to an explosive functional failure for a range of CBs and switchboards	• Maintain, or • Replace parts, or • Consider for replacement of CB
Leakage of insulating oil or SF_6 gas;	Leaking seals	In some instances, particularly with new CBS, the seals can be replaced or modified seals fitted to eliminate or significantly reduce the leaks. In older SF_6 CBs, often little can be done and this produces an environmental impact due to the significant global warming potential of escaped SF_6 gas. Rarely deteriorates to explosive functional failure due to gas pressure monitoring and alarms via SCADA[1].	• Drives consideration for replacement in small oil CBs due to the risk of explosive failure; • May contribute to the consideration for replacement in SF_6 CBs depending on the severity of the leak and the company's view of monetisation of green-house gas emissions.

[1] An explosive failure occurred due to low SF_6 pressure in the 66kV CB at Hazelbrook ZS not long after commissioning due to the valves between the gas manifold where the pressure sensor was located and the breaking chamber being inadvertently left shut during and after commissioning. As a result, the gas sensors incorrectly read normal pressure even though the breaking chamber was not pressurised with SF_6. A flash-over eventually occurred when the CB tried to break fault current. However, the explosion was contained within the CB chambers and the CB was able to be repaired and returned to service.

Conditional failure/defect	Typical cause	Comments	Typical response
		Leaking insulating oil in the older small oil CBs is topped up through maintenance. Levels are only able to be checked visually on site and given the small oil volumes presents in these CBs, this defect presents a risk of deteriorating to explosive functional failure and is a factor which drives consideration for replacement.	
Corrosion of casings	Caused by age and exposure to the weather and/or poor quality manufacturing and/or failure of seals over time	May possibly be repairable to some extent but is generally a factor contributing to the consideration for replacement	• Consideration for replacement

Response to functional failures (Failure modes and effects)

Functional failures of circuit breakers, apart from instances of failure to close, are very uncommon. However, the consequences of the failures can be significant. The responses to the failures also vary depending on the failure mode and the type, location and age of the circuit breaker involved. The table below summarises the possible consequences of and responses to, a typical range of functional failures.

Failure mode	Typical cause	Type of failure	Consequences of failure (CoF)	Typical response to the failure
Slow opening	• Issues with lubrication • Wear of mechanism • Trip coil burn out	Risk of explosive functional failure in all types of CBs	• Busbar section will be isolated • Possible unserved energy depending on substation topology	• Stand-alone CB – replace CB • Aged switchboard – replace switchboard • Modern switchboard – replace CB
Slow closing	• Issues with lubrication • Control relay failure • Wear of mechanism	Becomes a functional failure if it stops the CB carrying out its switching function.	• Varies from inconvenience of frustrating operator's attempts to switch the network to loss of supply to customers with a subsequent monetary value of unserved energy.	• Maintain, or • Replace parts, or • Consider replacement of CB
Low insulation resistance	Break down of insulation, usually due to moisture ingress	Risk of explosive functional failure	• Busbar section will be isolated • Possible unserved energy depending on substation topology	• Stand-alone CB – replace CB • Aged switchboard – replace switchboard • Modern switchboard – replace CB

High contact resistance	Wear of contacts due to use, and or wear of arc-quenching components	Risk of explosive functional failure	• Busbar section will be isolated • Possible unserved energy depending on substation topology	• Maintain, or • Replace parts, or • Consider for replacement of CB
Bushing dielectric loss-angle	Break down of insulation, usually due to moisture ingress	Risk of explosive failure of the bushing.	• Busbar section will be isolated • Possible unserved energy depending on substation topology	• Replace bushing if standalone bulk-oil CB such as GCN; • Replace switchboard if CB is in a switchboard
Discharge across insulation	Pollution on insulation surface Breakdown due to deterioration with age or manufacturing defects	Risk of explosive failure for a range of CBs and switchboards	• Busbar section will be isolated • Possible unserved energy depending on substation topology	• Stand-alone CB – replace CB • Aged switchboard – replace switchboard • Modern switchboard – replace CB
Leakage of insulating oil or SF_6 gas;	Leaking seals	Leaking oil presents a risk of explosive functional failure. Leaking SF_6 less likely to reach functional failure state due to gas pressure monitoring and alarms via SCADA and low pressure lock-out functionality.	• Busbar section will be isolated • Possible unserved energy depending on substation topology	• Replace oil CB; • Consideration for replacement of SF_6 CBs depending on the severity of the leak and the company's view of monetisation of green-house gas emissions.
Corrosion of casings	Caused by age and exposure to the weather and/or poor quality manufacturing and/or failure of seals over time	May deteriorate to functional failure of the control systems	• Varies from inconvenience of frustrating operator's attempts to switch the network to loss of supply to customers with a subsequent monetary value of unserved energy.	• Consideration for replacement

Failure risk consequences

The consequences of failure of circuit breakers varies with the type of CB, the insulation it uses and its location in the network. The risk profile presented in section 4 is an average across the fleet of circuit breakers and will change as older oil insulated circuit breakers are replaced with modern vacuum insulated units which have reduced consequences of failure.

Health score

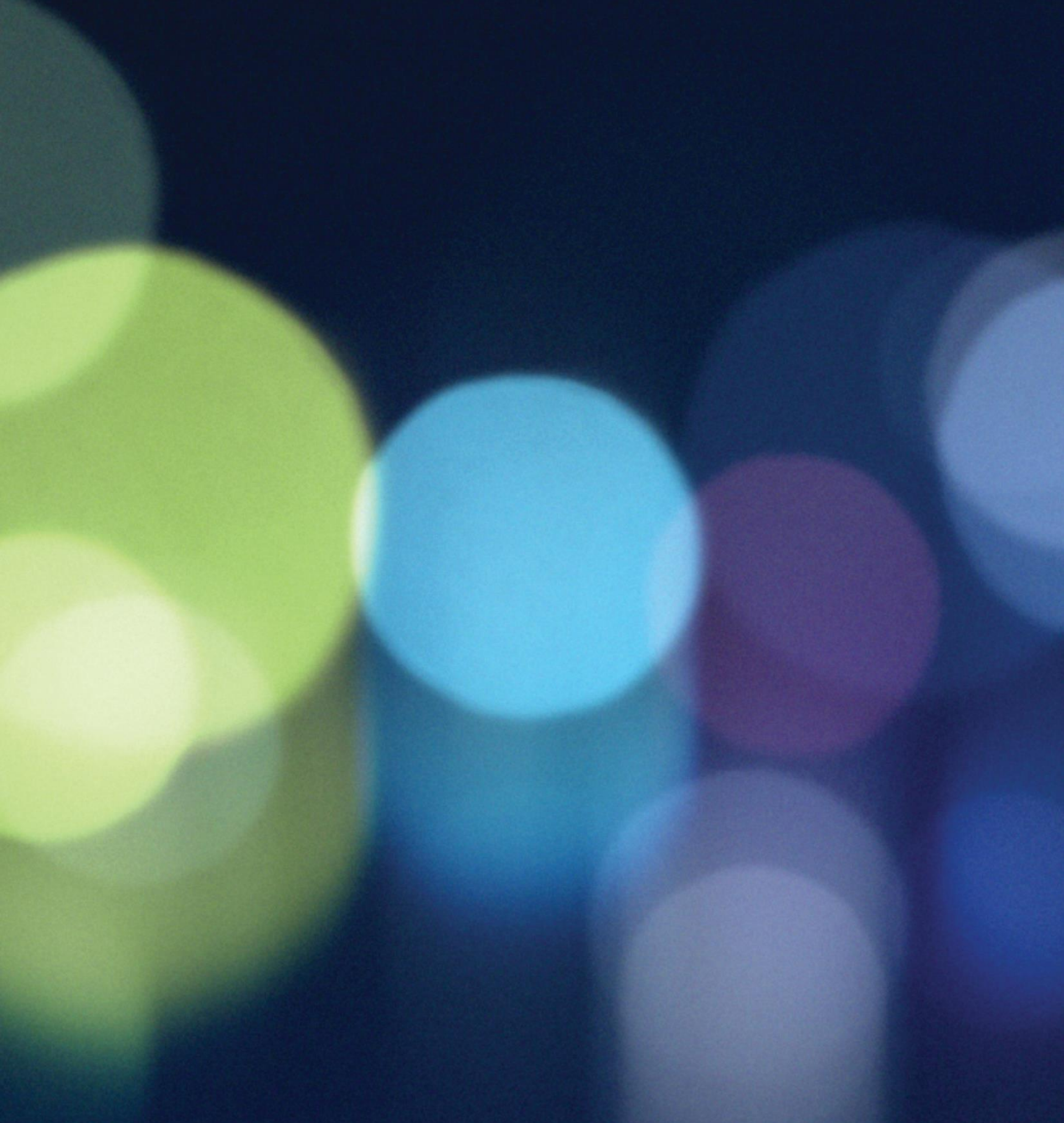
Health score is described in Substation Maintenance Instruction SMI 161 *Condition assessment of assets using health index* but is currently not effectively implemented as it cannot be directly linked to an asset PoF.

The purpose of the health score is to indicate where the CB is in its life from new to end of life – and in particular to allow an appropriate probability of failure to be applied to the asset. PoF for non-repairable failures is based on a Weibull function which is heavily reliant on the age of the asset. Alternative health score measures (e.g. CNAIM) will be investigated to further improve the development of individual asset level PoF curves.

In the interim a surrogate form of health score has been applied in the form of a conditional age which then will influence the PoF through adjusting the age of the asset. This is a reasonable approach for a snapshot of a range of assets at a particular time but is not suitable for mapping the deterioration trend of an asset over time. Therefore, it is used as a temporary measure to help differentiate between CBs in the interim until health scores become readily available

The conditional age of each circuit breaker is adjusted based on the level of additional fault-based and condition-based maintenance required of the breaker over the last 10 years and averaged on an annual basis. The economic costs reflecting the environmental impact of SF_6 gas leaks over the last five years is also calculated for inclusion with the additional maintenance costs to reflect the total service cost of each breaker on an annual basis. As noted above however, currently the value of the SF_6 leakage is not included in the final cost benefit assessment.

Switchboards which encompass a number of circuit breakers are assessed as a single asset for the cases where the destructive functional failure of any constituent breaker will result in the need to replace the entire switchboard. This is generally the case where the circuit breakers are insulated with oil and also for the earlier designs of SF_6 and vacuum circuit breaker switchboards without full air-tight compartmentalisation between each circuit breaker and each busbar chamber.



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