Asset Management Plan – High Voltage Circuit Breakers

Power and Water Corporation

CONTROLLED DOCUMENT

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Executive Summary

Power and Water Corporation (Power and Water) owns and operates the electricity transmission and distribution networks in the Northern Territory of Australia. Included in the networks are High Voltage (HV) circuit breakers which perform a critical function in maintaining the business objectives of delivering a safe and reliable supply of electricity to Power and Water's customers.

Assets contribute a sizeable proportion to the total asset base *– only a relatively small number of circuit breakers are close to the end of their expected serviceable lives*

HV circuit breakers make up 6% of the total network value of the asset base. It is a fairly young asset fleet, but varies by voltage level. The 132 kV circuit breakers have the oldest average age as the lower voltage levels have been subject to renewal programs during the past few years. There are approximately 37 circuit breakers that currently exceed their expected serviceable life and are generally in poor condition, but there are projects in place to address this risk.

Assets operate across a diverse environment *– temperature, humidity, rainfall, termites, soil types present a challenge to managing the assets.*

The Power and Water power network is subject to unique environmental and operational challenges ranging from the coastal tropical environments prone to cyclones, high temperatures and humidity, and high annual rainfall, to desert environments subject to high ambient temperatures, occasional flooding, and surrounding factors including high termite infestation and aggressive soil conditions. This unique environment results in a more rapid rate of asset deterioration, and lower worker productivity compared to peer distribution businesses.

The key impact by these climatic conditions is high moisture content in insulation oil, particularly for 'free breathing' type circuit breakers. This has resulted in the deterioration of a specific type of circuit breaker and emergence of a type issue.

Asset management challenges *– emerging type issues and data integrity.*

In general, the asset fleet is young and the projects planned to be implemented by the end of FY24 will remove a significant portion of the existing network risk. However, there are some emerging issues that need to be monitored to avoid major failures and outages. The key issues are SF6 gas leakage, amounting to approximately 130 kg per year and three circuit breakers that are unable to be effectively maintained in situ or removed from service. They are currently assessed as critical (C3) but in good condition (H1).

Focused routine inspections and targeted inspections and testing prioritising high risk areas are some of the proposed undertakings aimed at improving efficiency and improving data collection and analysis during business as usual activities. Improved data will enable more advanced analysis and modelling to be undertaken to better support asset management decision making

Investment programs are targeted to manage the key challenges – directed replacement.

In addition to a number of project that are currently under way and that will be completed during the current regulatory period, there are a number of augmentation and asset renewal programs are proposed for the 2019/20 to 2023/24 regulatory period:

- Establishing a new Wishart ZSS
- Replacement of the HLC circuit breakers due to a type issue
- Renewing Berrimah, Humpty Doo and Centreyard ZSS to address condition and safety concerns

The augmentation and renewal projects have been developed with the objective of managing the network risk. This risk would grow overtime as the demand increases and circuit breaker condition deteriorates. The projects selected for the next regulatory period will mitigate the excessive network risk and return it to a level that is sustainable in the long term.

The power transformer programs are summarised as follows:

Investment category	2019-20 ($ million)	2020-21 ($ million)	2021-22 ($ million)	2022-23 ($ million)	2023-24 ($ million)	Total ($ million)
Augmentation	$0.00	$0.00	$1.65	$1.83	$1.61	$5.09
Renewal	$1.62	$1.53	$1.19	$0.54	$0.00	$4.88
Maintenance Plans	$1.28	$1.28	$1.28	$1.28	$1.28	$6.40
Total	**$2.90**	**$2.81**	**$4.12**	**$3.65**	**$2.89**	**$16.37**

Benefits from the investment program *– network risk*

The investments are not expected to impact the system performance directly, however, they will reduce the total risk on the network and reduce the operational expenditure required at these substations. The reduction of risk on the network is shown through the asset health assessment and criticality assessment.

Table 0.1 shows the current network risk. Table 0.2 shows the network risk at the end of the next regulatory period once the above mentioned projects have been completed. The tables demonstrate there will be a reduction in network risk, bringing it to a sustainable level that is suitable for Power and Water.

Table 0.1 Current circuit breaker risk matrix

	H1	H2	H3
C1	435	36	49
C2	6	0	6
C3	35	0	3

Table 0.2 Circuit breaker risk matrix with investment

	H1	H2	H3
C1	479	33	25
C2	9	0	3
C3	37	0	1

1 Purpose

The purpose of this asset management plan (AMP) is to define Power and Water Corporation's (Power and Water) approach to managing its high voltage circuit breakers located in zone substations. It frames the rationale and direction that underpins the management of these assets into the future:

- Short Term (0-2 years): Detailed maintenance and capital works plans for the upcoming financial year based on current asset condition.
- Medium Term (3-7 years) 2019-24 Regulatory Control Period: Strategies and plans based on trends in performance and health indicators.
- Long Term (8-12 years) 2024-29 Regulatory Control Period: Qualitative articulation of the expected long-term outcomes.

The HV circuit breaker assets are managed to comply with the broad external requirements of legislation, codes and standards. This is achieved within an internal framework of policy, strategy and plans that are enabled through interrelated documents, systems and processes that establish the Power Networks asset management practices. The asset management system is summarised in Figure 1-1.

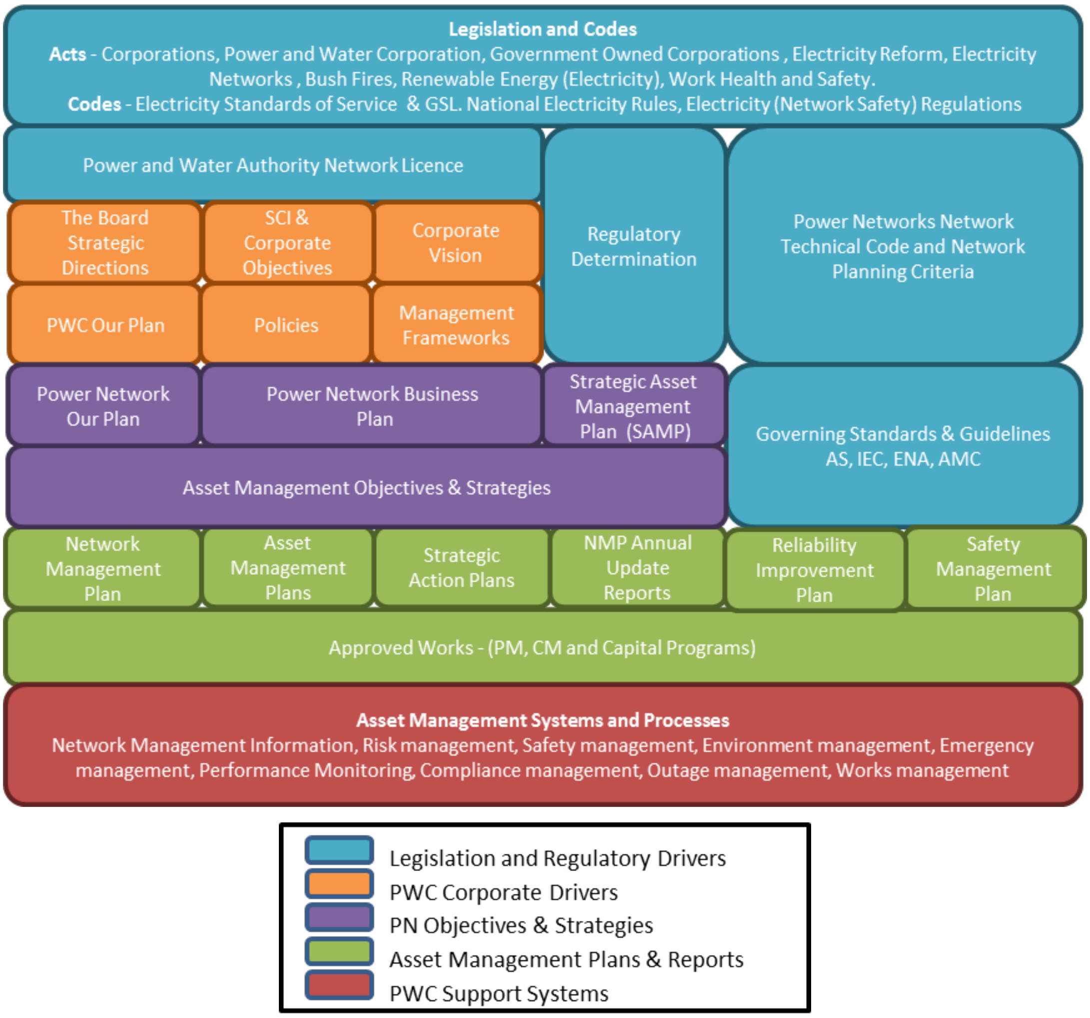

Figure 1-1 Asset Management System

2 Scope

2.1 Asset class overview

In-scope assets include all HV circuit breaker located within securely fenced zone substations with nominal primary voltages between 11 kV and 132 kV. The asset group excludes power transformers and other HV assets located within the zone substation boundaries.

This AMP also does not include instrument transformers, auxiliary transformers, surge arresters, protection equipment (e.g. HV fuses, relays, etc.), DC systems, SCADA, DSA and Load Control (Frequency Injection) equipment, buildings, fences and other civil infrastructure within zone substations.

Table 2.1: Overview of in-scope assets at 30 June 2017

Voltage kV	Quantity	Economic lifespan (years)	Average age (years)	Number exceeding economic lifespan in forecast period		Average remaining life of assets not exceeding economic lifespan (years)
				Qty	%	
11 kV	300	45	16.0	20	6.7%	28.5
22 kV	126	45	16.9	13	10.3%	29.4
66 kV	104	45	18.2	3	2.9%	27.7
132 kV	40	45	23.8	-	0.0%	21.4
Totals	**570**	**45**	**17.1**	**36**	**6.3%**	**27.9**

Further information on Power and Water's high voltage circuit breakers assets, such as quantities, locations, manufacturers, types, etc. in given in Appendix B – Asset data.

The high voltage circuit breaker asset class comprises a significant proportion of Power and Water's assets and drives a number of inspection and maintenance activities. This is due to the criticality of the assets and the aggressive nature of the environment in which they are located.

2.2 Asset class function

Power and Water has a unique network with a small customer base split across three separate networks of Darwin-Katherine, Alice Springs and Tennant Creek. HV circuit breakers belonging to this asset class are located in zone substations and perform the function of energising and de-energising the parts of the distribution system to which they are connected, particularly when it is necessary to disconnect those sections which suffer electrical faults in order to minimize the effects of those faults on the system as a whole. The generic location of zone substations within the electricity network is shown in Figure 2-1.

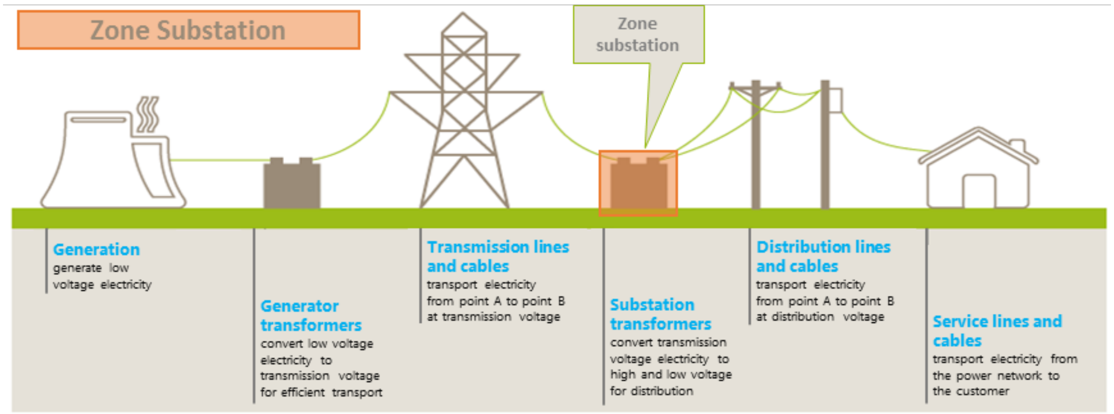

Figure 2-1: Diagram of in-scope assets

HV circuit breakers are located upstream from other assets such as transformers, switchboards or feeders and operate to protect those assets as described above. Their operation can be triggered manually (locally or by SCADA), and automatically by a signal received from the protection relay system.

They can be located both outdoor and indoor, and are predominantly located on the fringes of the urban and suburban areas which they supply.

The capability of a circuit breaker to perform at the desired level is assessed through its condition, defect history, age, reliability and compliance with standards. The potential for non - performance is assessed through a risk management approach.

2.3 Asset objectives

The AMP provides a framework which steers the management of the asset class in a manner that supports the achievement of Power and Water's broader organisational goals. The Asset Management strategies are listed in the Strategic Asset Management Plan (SAMP) and are aligned to the Asset Management Objectives and implemented in through Asset Management Plans (specific to asset class) or Strategic Asset Plans as shown in Figure 2-2.

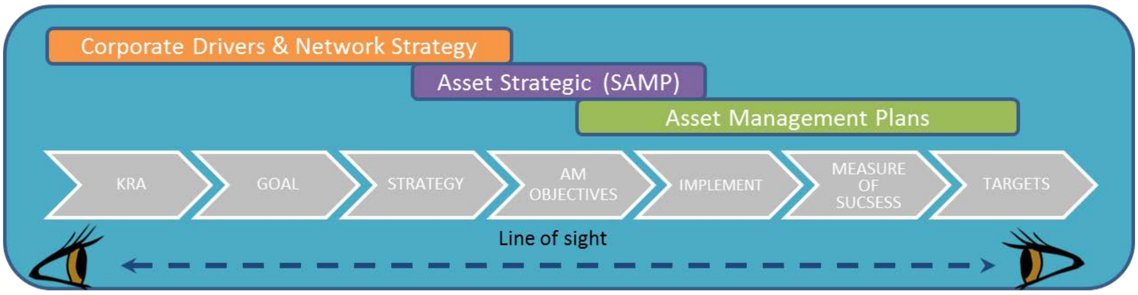

Figure 2-2 Asset Management Line of sight from Corporate and Network strategies through the Asset Management objective to the targets in the asset management plan.

Table 2.2provides the asset management objectives from the strategies that are relevant to this asset class along with the measures of success and the targets. This provides a 'line of sight' between the discrete asset targets and Power and Water corporate Key Result Areas.

Table 2.2 Asset Management Objectives, Measures of Success and Targets

Objectives	Measures	Targets
• Network related operation and maintenance tasks are quantified in terms of risk and used to inform investment decisions that affect Health and Safety outcomes for the organisation • Safeguard persons, property and equipment in the event of system faults or abnormal operating conditions.	• Total asset class specific safety incidents	• Total asset class specific safety incidents not exceeding TBA
• All environmental risks have been defined, mitigation controls implemented and responsibility for risk ownership has been assigned to appropriate leaders • Develop Environmental Improvement Plans for significant risks to reduce risk exposures and tracked through a governance framework • Develop performance indicators for intended environmental outcomes.	• Total asset class specific environmental incidents associated. • SF6 Leakage per year	• Total asset class specific environmental incidents associated not exceeding TBA
• Ensure that the systems and processes provide sufficient and appropriate data and information to drive optimal asset and operating solutions. • Minimise disruption to supply availability and quality in the event of system faults or abnormal operating conditions	• Asset class contribution to system SAIDI • Asset class contribution to system SAIFI • GSL contribution per year Guaranteed Service Levels	• SAIDI for this asset class TBA • SAIFI for this asset class TBA • GSL contribution per year TBA
• Ensure that the systems and processes provide sufficient and appropriate financial data • Understand the financial risks associated with asset management	• Variance to AMP forecast CAPEX • Variance to AMP forecast OPEX	• Variance to AMP forecast CAPEX +/-10% • Variance to AMP forecast OPEX +/-10%
• Develop systems and data that facilitate informed risk based decisions • Ensure that works programs optimise the balance between cost, risk and performance • Ensure the effective delivery of the capital investment program	• Network risk index quantified (Y/N) • Health and Criticality Parameters defined (Y/N)	• Achieved
• Identify, review and manage operational and strategic risks • Prioritise projects, programs and plans to achieve efficient and consistent risk mitigation. • Achieve an appropriate balance between cost, performance and risk consistent with regulatory and stakeholder expectations. • Define and communicate the level of risk associated with the investment program	• Critical spares analysis completed for asset class • Operator/Maintainer risk assessment completed for asset class and risk register updated	• Achieved
• Ensure that electricity network assets are maintained in a serviceable condition, fit for purpose and contributing positively to Power Networks business objectives.	• All staff are trained and hold appropriate qualifications for the tasks they undertake. • Peer benchmarking, i.e. a reasonableness test of underlying unit costs (capex, opex) • Asset class preventative maintenance completion	• Achieved

3 Context

3.1 Roles and responsibilities

Power and Water uses an “Asset Owner / Asset Manager / Service Provider” business model. Although there is extensive collaboration and interfacing between the roles, the following general principles apply:

- The Asset Owner establishes the overall objectives for the assets;
- The Asset Manager develops the strategies and plans to achieve the objectives; and
- The Service Provider performs activities on the ground to deliver the plans.

3.2 RACI

Section 3.1 sets out the organisational roles and responsibilities. This section sets out the Responsibility, Accountability, Consulted, Informed (RACI) matrix for this asset class. This defines the roles and accountabilities for each task by allocating to specific roles/personnel in Power and Water.

Table 3.1 RACI matrix for power transformers

Process	Exec GM Power Networks	Group Manager Network Assets	Chief Engineer	Network Planning Manager	Major Project Delivery Manager	Southern Delivery Manager	Group Manager Service Delivery	Substation Services Manager	Test & Protection Manager	Works Management Manager	Strategic Asset Engineering	Asset Quality & Systems
Establish Condition Limits		A	C	C		I	I	C/I	C/I	I	R	I
Performance and condition data analysis	I	A	I	I		I	I	I	I	I	R	I
Plan capital works (Options, costs, BNIs, BCs etc)	I	R	A		C/I	R	R	C/I	C/I	R	R	I
Execute maintenance plans	I	I	I			A	A	R	R	R	C/I	I
Deliver identified major projects and programs of work	I	C	A	C	R	R	R	R	R	C/I		
Manage asset data (data entry, verify data)		A	I	I				I	I		C/I	R
Monitor delivery of capital plans and maintenance	I	A	I	I	I	R	R	R	R	R	R	R

- *Accountable **(A)** means the allocated person has an obligation to ensure that the task is performed appropriately*
- *Responsible **(R)** means the allocated person must ensure the task is completed*
- *Consulted **(C)** means the allocated person must be included in the process for input but do not necessarily have specific tasks to do*
- *Informed **(I)** means this person must be kept up to date with progress as it may impact other parts of their responsibilities or accountabilities.*

3.3 Identification of needs

With respect to asset replacement, the identification of needs is guided by the risk profile for the asset. Table 3.2 below provides the guiding principles for the adoption of the most appropriate asset management strategy.

Table 3.2: HV circuit breaker asset management strategy overview

Asset Management Strategy	Asset risk profile suitability
Reactive (functional failure)	• HV circuit breakers are high value assets and therefore are not intentionally run to failure. From time to time, assets do fail in service; however, all reasonable and appropriate measures are taken to prevent this occurring.
Condition-based (conditional failure)	• HV circuit breakers are typically critical assets and functional failure is likely to result in loss of supply to customers, or pose environmental or safety risks • Condition data is gathered regarding asset condition and used to forecast optimal timing for replacement • Asset condition modelling is done, based on actual data, to assist prioritisation of asset replacement • Condition-based replacement is forecast using a probabilistic/risk-based approach which involves a cost benefit analysis to ensure the proposed replacement option is optimal
Demand-driven	• The forecast demand at a substation, and growth/reduction over time, is forecast to identify when the existing installed capacity is insufficient for the demand and augmentation of the substation is planned
Customer-driven	• Large (HV) customers connecting to the network may require a dedicated feeder. These issues are managed through the connections process when they occur.

3.4 Selection of options and solutions

Once a circuit breaker is identified as being in poor condition or being insufficient to meet forecast load, a comprehensive set of options is considered to address the risk and ensure safe and reliable supply of power can be maintained. The suite of options should consider the solutions set out in Table 3.3 below, as relevant for the unique situation being assessed.

Table 3.3: Example options that should be considered

Asset Management Options	Asset risk profile suitability
Repair / life extension	• Applicable to condition based strategy only • Asset returned to “as good as old” condition (repair) or “better than old” (life extension) • Major refurbishments are not considered to provide significant life extension and therefore are not generally undertaken.
Like-for-like	• Replace the circuit breaker with a modern equivalent of the same (or similar) capacity. For transformer circuit breakers, capacity may need to be increased to remove a constraint or to align with upstream transformers.

Alignment with other assets	• When circuit breakers are replaced, other assets at the zone substation, such as protection and instrument transformers, may also require replacement. Economic analysis is undertaken to assess the most efficient option of aligning asset replacement or undertaking them as separate projects.
Network solution	• Temporary or permanent transfer of load to other substations to defer the need for augmentation or reduce energy at risk in case the failure of a poor condition circuit breaker. This may be achieved through switching existing network or building new feeders.
Demand management/Non-network solutions	• Incentivizing customers to reduce their demand at peak times to defer the need to augment substation capacity or build new feeders. • Generator support to meet peak demand

4 Asset base

4.1 Overview

Power and Water owns, operates and maintains a portfolio of 570 zone substation-based HV circuit breakers across the Northern Territory. Power and Water operates HV distribution networks at 11 kV, 22 kV, 66 kV and 132 kV.

The HV circuit breaker fleet includes assets that are currently in service have were installed in 1964 through to today. This has resulted in a range of technologies, manufacturers and models.

4.2 Asset types

The HV circuit breaker fleet as of 30 June 2017 comprises 570 circuit breakers, operating at 11 kV, 22 kV, 66 kV and 132 kV, using oil, SF_6 and vacuum interrupting media, in 32 zone substations and 5 switching stations across Darwin, Katherine, Alice Springs and Tennant Creek.

Table 4.1: HV circuit breaker volumes by region and voltage level

	VOLTAGE LEVEL				
REGION	**11**	**22**	**66**	**132**	**Total**
ALICE SPRINGS	17	36	10		63
DARWIN	278	37	89	36	440
KATHERINE	5	31	5	4	45
TENNANT CREEK		22			22
TOTAL	**300**	**126**	**104**	**40**	**570**

A detailed breakdown of numbers by substation is in Appendix B – Asset data.

4.3 Breakdown of asset population

HV circuit breakers installed on Power and Water's network vary according to several key characteristics which can affect the asset management regime applied to individual assets. These characteristics include: rated voltage; age; interrupting medium; whether they have grounded (dead tank) or insulated (live tank) interrupting chambers; and manufacturer/model.

4.3.1 Voltage and type

HV circuit breakers can be located indoors and outdoors and with interrupting media including oil, SF_6 gas and vacuum. They can be either dead or live tank arrangements. These characteristics are described below and summarised in Table 4.2 according to combinations of these parameters used in Power and Water's network.

- Indoor circuit breakers are located within a building and therefore have some protection from the climate. They are generally set up as a switchboard with each circuit breaker immediately adjacent to the next. Table 4.2 shows that lower voltage circuit breakers (11 kV and 22 kV) are predominantly indoor installations.
- Outdoor circuit breakers are located in a switchyard and are individual units separated by distanced as required for electrical clearances and operational needs. Table 4.2 shows higher voltages (66 kV and 132 kV) are predominantly outdoor.
- Insulating media commonly used include vacuum, oil or SF6 gas. The insulating media enables the clearances to earthed surfaces to be reduced without arching and therefore reduces the size of the circuit breaker. Vacuum circuit breakers are used for 11 kV and 22 kV circuit breakers but higher voltage levels of 66 kV and 132 kV use either oil or SF_6 as their interrupting medium.
- Live tank circuit breakers have the interrupting chamber at the line potential. The interrupting chamber therefore requires insulated supports and results in a high centre of gravity and maintenance is undertaken above ground level (requiring elevated work platforms)
- Dead tank circuit breakers have the interrupting chamber at ground potential. The conductors enter the interrupting chamber through insulated bushings. The interrupting chambers are at ground level so maintenance activities are easier to conduct. 90% of all circuit breakers on Power and Waters network are dead tank, including all indoor circuit breakers.

Table 4.2: HV circuit breaker quantities by type and voltage level

			VOLTAGE LEVEL				
INDOOR / OUTDOOR	DEAD / LIVE TANK	INTERRUPTING MEDIUM	11	22	66	132	Total
INDOOR	DEAD	OIL	27				27
INDOOR	DEAD	SF6	1	25	29		55
INDOOR	DEAD	VAC	272	83			355
OUTDOOR	DEAD	OIL		13	2		15
OUTDOOR	DEAD	SF6			33	25	58
OUTDOOR	DEAD	VAC		5			5
OUTDOOR	LIVE	OIL			36		36
OUTDOOR	LIVE	SF6			4	15	19
Total			**300**	**126**	**104**	**40**	**570**

4.3.2 Voltage and manufacturer

Power and Water has used a wide range of manufacturers, though Siemens has now become, the predominant supplier, followed by GEC and ABB.

	VOLTAGE LEVEL				
Manufacturer	**11**	**22**	**66**	**132**	**Total**
SIEMENS	87	68	61	2	218
GEC	54	15			69
ABB	36	18	2	3	59
REYROLLE	36				36
ASEA			35		35
AREVA	34				34
HITACHI			3	22	25
UNKNOWN	10	8	1	3	22
HAWKER SIDDELEY	18				18
SOUTH WALES	18				18
YORKSHIRE		14			14
ALSTOM		3	1	6	10
SCHNEIDER	7				7
AEG				4	4
EIB			1		1
Total	**300**	**126**	**104**	**40**	**570**

Table 4.3 HV circuit breaker volumes by manufacturer and voltage class

Of the 570 HV circuit breakers in service at 30 June 2017, Siemens manufactured 218. However, Siemens only started supplying HV circuit breakers to Power and Water in approximately 2005; of the 367 HV circuit breakers installed since 2005, Siemens has supplied approximately than 60%.

4.3.3 Failure modes and consequences

Table 4.4 describes the common failure modes of circuit breakers and their consequences.

Failure mode	Description
Insulation degradation	Depending on the insulation medium(s), deterioration can occur as result of age, moisture ingress, partial discharge and/or contamination. Insulation failures are often catastrophic in nature and often damage nearby assets, particularly for oil insulated units where there is a risk of fire. Failure during manual switching operations is a particular concern for personnel safety as this is the most likely time for a failure to occur other than

Failure mode	Description
	during a fault interruption. The consequences to personnel are then dependant on the operator protection afforded by the design of the circuit breaker or switchboard and PPE worn.
Contact wear	Contact wear is typically related to the number of operations, as well as quality of maintenance to ensure contacts are aligned and penetrate to within specifications. Contact wear can cause various failure mechanisms to develop, such as high resistance connections and subsequent thermal runaway, causing damage to insulation and eventually failure.
Operating mechanism issues	Operating mechanism failure is typically related to age and number of operations. Poor maintenance practices including inappropriate component lubrication, failure to replace worn parts, contamination due to operating environment can all contribute to premature mechanism wear. Depending on the component of the mechanism that fails, impact on operation can vary from failure to open or close within timing limits, failure to latch or recharge operating springs, misalignment of contacts, etc. These issues can and often lead to circuit breaker failure, and most commonly lead to reliability impacts due to delays to fault restoration.

Table 4.4 Common circuit breaker failure modes

4.4 Type issues

A type issue is a problem that affects all assets of the same make and model such that they all fail in a similar failure mode or exhibit the same problems during inspection and maintenance. This may or may not result in a need for early replacement of the asset type and is assessed on a case by case basis.

The following sections list the current and emerging type issues on Power and Waters network.

4.4.1 66 kV ASEA HLC circuit breakers

The main type issue that is currently affecting Power and Waters circuit breakers is regarding the 66 kV ASEA HLC circuit breakers. These were manufactured by ASEA and installed on Power and Waters network between 1972 and 1986.

The factors that have identified these assets as having a type issues include:

- Consistently poor performance results for their functional and electrical tests
- Common issues identified amongst the fleet during inspection and routine maintenance
- High historical cost associated with maintaining the asset type
- Routine maintenance requirement more frequently than for other circuit breaker types
- Higher rate of failures and need for non-routine maintenance than experienced for other circuit breaker types

These issues are discussed below, demonstrating the type issue with the HLC circuit breaker fleet.

Table 4.5 provides an overview of the locations, ages and quantities of these assets.

Zone Substation	Type	No. of CBs	Asset Age
Berrimah (BE)	HLC 72.5 / 1600	5	37
Casuarina (CA)	HLC 72.5 / 1600	2	37
	HLC 72.5 / 1600	3	40
	HLC 72.5 / 1250	1	40
Cox Peninsula (CP)	HLC 72.5 / 1600	1	44
Hudson Creek (HC)	HLC 72.5 / 2000U	1	27
	HLC 72.5 / 2000U	10	31
Humpty Doo (HD)	HLC 72.5 / 1250	1	40
Palmerston (PA)	HLC 72.5 / 1600	5	34
Pine Creek (PC)	HLC 72.5 / 1600	1	40
Weighted average age / total assets			35

Table 4.5 Overview of HLC asset fleet

Common issues found during maintenance

The key issues that are affecting this asset fleet and causing the poor performance are:

- Water in oil – the HLC circuit breaker is a “free-breathing” design, so in the humid and wet environment of the Northern Territory, moisture enters the circuit breaker to the extent that significant volumes of ‘free’ water (i.e. water below the oil) must be drained from the circuit breaker stacks at each maintenance outage. Recent outage reports indicate that the water-in-oil problem is becoming worse.
- Contaminated insulators – extreme environmental conditions result in greater surface contamination of the insulators than is advisable, resulting in an increased risk of tracking along the insulator surface.
- Cracked insulating rods – Power and Water believes that a batch of non-OEM insulating rods was procured at some time in the past, which wear more quickly and tend to develop cracks more easily than OEM components, resulting in replacement rods being required more frequently than expected.
- Limited OEM support – ABB is continuing to support the HLC range for the time being; however, the HLC no longer features in its new equipment product line, ABB preferring to offer SF_6 and CO_2 as the interrupting medium instead. Future support is not assured beyond the next few years.
- Limited spare components – the retirement of 14 1,250 A and 1,600 A CBs provides an opportunity to cannibalise the retired units for spare parts. However, none of the retired CBs will be 2,000 A rated, so any current rating dependent components that are cannibalised cannot be used on the larger units.

High historical cost

Out of 121 circuit breakers, in the past 5 years, that required corrective maintenance to meet functional specifications and to be returned to service, 30 were HLC type (100% of the HLC fleet). This is an over representation of one type of circuit breaker and further demonstrates the type issue.

Expenditure records, summarised in Table 4.6, of the five financial years between 2012/13 and 2016/17 show that Power and Water has recorded operational expenditure on maintenance of over $815,000, an average of more than $5,400 per CB per annum. The breakdown by zone substation is shown in the following table:

Table 4.6: HLC circuit breaker opex history

Zone Substation	Type	5-year opex	Average opex per annum per CB
Berrimah (BE)	HLC 72.5 / 1600	144,742	5,790
Casuarina (CA)	HLC 72.5 / 1600	137,729	5,509
	HLC 72.5 / 1250	17,856	3,571
Cox Peninsular (CP)	HLC 72.5 / 1600	54,559	10,912
Hudson Creek (HC)	HLC 72.5 / 2000U	279,278	5,078
Humpty Doo (HD)	HLC 72.5 / 1250	20,916	4,183
Palmerston (PA)	HLC 72.5 / 1600	140,690	5,628
Pine Creek (PC)	HLC 72.5 / 1600	19,763	3,953
Total opex / average per annum per CB		815,532	5,437

Note that the higher cost of maintaining the CBs at Cox Peninsula ZSS relates to the additional time involved in travelling to the substation from the maintenance depot in Darwin.

Routine and non-routine maintenance

The planned maintenance frequency of the CBs is historically shorter than the two years expected by Power and Water, as demonstrated by the breakdown in Table 4.7. Between 2012/13 and 2016/17, there were 135 routine outages of HLC CBs. Overall, the average maintenance frequency for routine outages was slightly over one year (1.11 years).

Table 4.7: HLC circuit breaker routine maintenance outages

Zone Substation	Type	5-year maintenance outages	
		Routine	Average per annum per CB
Berrimah (BE)	HLC 72.5 / 1600	24	0.96
Casuarina (CA)	HLC 72.5 / 1250	4	0.80
	HLC 72.5 / 1600	14	0.56
Cox Peninsular (CP)	HLC 72.5 / 1600	4	0.80
Hudson Creek (HC)	HLC 72.5 / 2000U	62	1.13
Humpty Doo (HD)	HLC 72.5 / 1250	4	0.80
Palmerston (PA)	HLC 72.5 / 1600	18	0.72

Zone Substation	Type	5-year maintenance outages	
		Routine	Average per annum per CB
Pine Creek (PC)	HLC 72.5 / 1600	5	1.00
Total outages / average per annum per CB		135	0.90

In addition, there were 68 non-routine and emergency outages, as shown by the breakdown in Table 4.8. The poor performance of the HLC circuit breakers is clearly reflected in the test results shown in section 5.1.1 above. This show that on average frequency, each HLC circuit breaker is expected to have an emergency outage once every 2 years. This is very frequent compared to the rest of the asset fleet.

Table 4.8: HLC circuit breaker emergency and non-routine maintenance outages

Zone Substation	Type	5-year maintenance outages	
		Emergency / non-routine	Average per annum per CB
Berrimah (BE)	HLC 72.5 / 1600	14	0.56
Casuarina (CA)	HLC 72.5 / 1250	1	0.20
	HLC 72.5 / 1600	15	0.60
Cox Peninsular (CP)	HLC 72.5 / 1600	6	1.20
Hudson Creek (HC)	HLC 72.5 / 2000U	20	0.36
Humpty Doo (HD)	HLC 72.5 / 1250	1	0.20
Palmerston (PA)	HLC 72.5 / 1600	9	0.36
Pine Creek (PC)	HLC 72.5 / 1600	2	0.40
Total outages / average per annum per CB		68	0.45

Due to the above mentioned issues and resulting risk presented by this asset type, a program has been established to remove all of these assets from the network during the FY20 to FY24 regulatory period. This is described in more detail in section 9.2.

4.4.2 Hitachi 66 kV OSYGB circuit breakers (three in fleet)

The Hitachi 66 kV OSYGB oil circuit breakers exhibit a range of age-related issues such as:

- cracks in the bushing sight glasses
- air leaks in the compressed air system and operating mechanisms
- slow operating times.

These circuit breakers have exceeded the estimated economic life of 45 years, so it is increasingly likely that they will require planned replacement within the next 5-10 years. Until then, repairs are effected as and when required.

4.4.3 ABB 132 kV PASS MO circuit breakers

The three ABB PASS MO SF_6 circuit breakers have proven extremely difficult to maintain, as they do not appear to have been designed with operation and maintenance requirements in mind. The main problem is that it is not possible to perform all the required tests in situ, so Power and

Water is concerned that should any significant problems develop, they will not be identified prior to them causing a circuit breaker failure.

4.4.4 SF_6 gas leakage

Power and Water operates a total of 120 circuit breakers that use SF_6 as the interrupting medium. An increasing number of these circuit breakers seem to require frequent top-ups of SF_6 gas at each maintenance outage:

- The 66 kV ABB EDF SK-1 type of circuit breaker (three in the fleet) require an average of 1 kg of additional gas at each outage
- The 132 kV Hitachi CFPT type located at Channel Island (22 in the fleet) require an average of 3-4 kg of additional gas per pole at each outage. The annual consumption of SF_6 gas in recharging these units is approximately 100-130 kg.

Apart from the cost of the replacement gas, loss of SF_6 of these amounts is a concern owing to its high global warming potential as a greenhouse gas of 23,900 times that of CO_2.

4.5 Asset profiles

4.5.1 Weighted average age

This section considers the weighted average age and weighted average remaining life (WARL) of the circuit breaker fleet. The WARL is useful to consider as it provides a single figure, high level metric that can be used to quickly identify areas of risk on the network where an entire sub category of the fleet is approaching the end of its serviceable life.

Table 4.9 provides a summary of the remaining asset life by voltage level across the entire fleet, while Table 4.10 provides a summary of remaining life broken down further by type. In both tables the remaining lives are calculated based on an estimated replacement life of 45 years.

Table 4.9: Average age and remaining life by voltage

Primary voltage	Weighted Average Age (years)	Weighted Average Remaining Life (years)	% of asset population
11 kV	16.0	29.0	52.6%
22 kV	16.9	28.1	22.1%
66 kV	18.2	26.8	18.2%
132 kV	23.8	21.2	7.0%
Total fleet	17.1	27.9	100.0%

By only considering the voltages levels as shown in Table 4.9 the asset fleet appears to be in reasonable condition when using age and remaining life as a proxy for condition. However, as shown in Table 4.10, breaking the asset classes down further reveals specific types that are beyond or approaching their expected life.

The assets that have an average age exceeding their expected lives are the 11 kV indoor oil circuit breakers and the 22 kV outdoor oil circuit breakers. These are both older technologies as typically indoor vacuum types circuit breakers are now used at these voltage levels.

66 kV outdoor oil circuit breakers are approaching their expected life and are therefore likely to be at an elevated risk of failure. These include the HLC type circuit breakers which are discussed further in section **Error! Reference source not found.**.

Table 4.10: Average age and remaining life by CB class

INDOOR / OUTDOOR	VOLTAGE kV	INTERRUPTING MEDIUM	AVERAGE AGE (YEARS)	AVERAGE REMAINING LIFE (YEARS)	% OF ASSET POPULATION
INDOOR	OIL	11	46.3	**-1.3**	4.7%
INDOOR	SF6	11	7.0	38.0	0.2%
INDOOR	SF6	22	23.4	21.6	4.4%
INDOOR	SF6	66	4.4	40.6	5.1%
INDOOR	VAC	11	13.0	32.0	47.7%
INDOOR	VAC	22	8.3	36.7	14.6%
OUTDOOR	OIL	22	54.0	**-9.0**	2.3%
OUTDOOR	OIL	66	37.2	**7.8**	6.7%
OUTDOOR	SF6	66	9.4	35.6	6.5%
OUTDOOR	SF6	132	23.8	21.2	7.0%
OUTDOOR	VAC	22	32.0	13.0	0.9%

4.5.2 Age profiles

This section considers the age profile of the circuit breakers. Where the WARL shows a high level view of where risk may exist, the age profile shows which asset are approaching or beyond their serviceable life. Since assets deteriorate over time due to use, switching actions and the environment, age is a useful proxy for condition.

Figure 4-1 shows the age profile of the entire circuit breaker fleet by voltage level. It shows that there is a peak in quantities installed between 30 and 49 years ago. This aligns to the rebuilding post cyclone Tracey and the expansion of the electricity network during the early 1980's.

More recently, there has been a large number of assets installed in the past 12 years. The volumes equate to 64% of all circuit breakers on the network have been installed since 2005. This was due to a need to renew the old and deteriorated assets and efforts to improve the network reliability after several system black incidents.

The relatively new fleet of assets is reflected in the network average age and WARL. The impact of this is potentially concealing the risk associated with aged assets when looking at high level metrics.

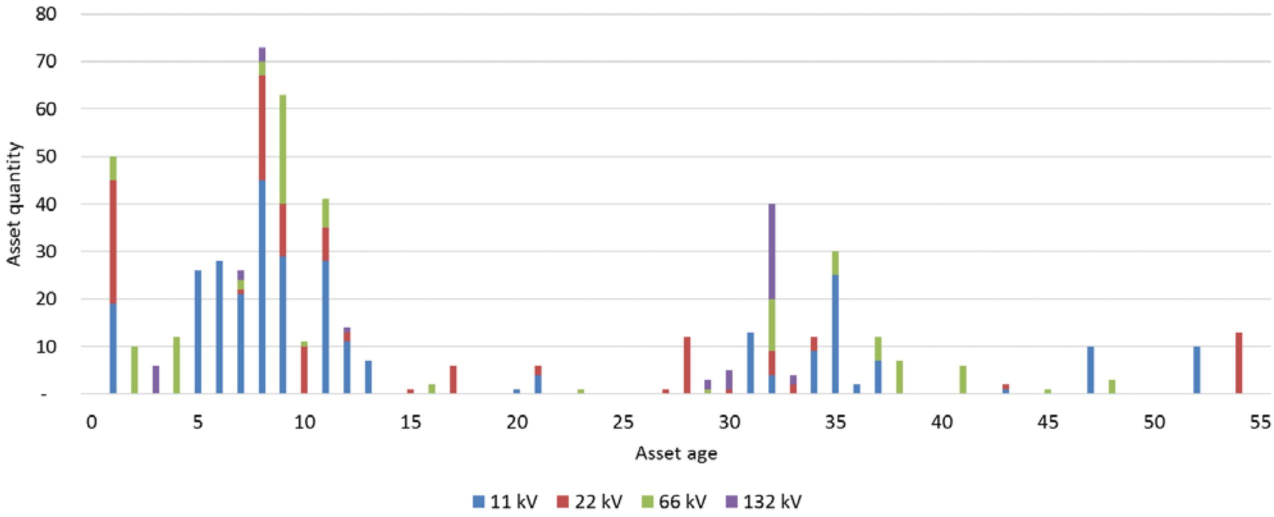

Figure 4-1 Circuit breaker age profile by voltage

Since the expected serviceable life of circuit breakers is 45 years, the chart clearly shows a number of circuit breakers that have exceeded that age. Table 4.11 shows the quantities of the assets.

VoltagekV	Quantity	Number exceeding currently economic lifespan	
		Qty	%
11 kV	300	20	6.7%
22 kV	126	13	10.3%
66 kV	104	3	2.9%
132 kV	40	-	0.0%
Totals	**570**	**36**	**6.3%**

Table 4.11 Quantities of assets that have exceeded their expected life

This indicates that there are 36 circuit breakers, or 6.3% of the fleet, that are potentially high risk and require further investigation to assess their condition to determine if they require replacement.

5 Health and criticality profiles

This section discusses the health, criticality and resulting network risk of the circuit breaker fleet. This analysis informs the priorities for Power and Water with respect to where they should focus further condition assessment and plan future network investments.

The health and criticality framework provides the basis for calculating the risk associated with protection assets. Risk is the product of the probability of an event occurring (determined by asset health) and the consequence should it occur (determined by asset criticality). Network risk can be reduced though improving the condition of assets (opex or repex) and/or by reducing the consequence of failure through changing the network topology/configuration.

Power and Water manages network risk so it can successfully operate the network safely and reliably at the lowest cost to the customer.

5.1 Asset health

As high value and critical assets on the network, circuit breakers are inspected, tested and maintained in-line with strategies developed by Power and Water based on the manufacturers inspection and maintenance manual, Power and Water test and maintenance procedures[1], internal and external circuit breaker and high voltage testing experts, as well as significant consultation with industry piers through regular asset management forums, industry working groups and continuous internal and external technical training. This ensures Power and Water is continually optimising its maintenance strategies with a clear understanding of industry best practice and taking advantage of technology advances of test equipment that reduces the time required for testing in the field.

Asset health is determined through assessments of multiple aspects of the circuit breaker, including visual inspections and testing. These inspection methods are discussed further in the following sections.

5.1.1 Functional and electrical tests

There are three key tests that are applied to circuit breakers:

- **Insulation resistance:** measures the resistance, measured in giga ohms, between active (electrically live) parts and earthed surfaces. If the resistance is too low, then there is the risk of flash over/arcing which can destroy the circuit breaker and potentially adjacent assets.
- **Contact resistance:** measures the resistance, measures in micro ohms, between the contacts of the circuit breaker. If resistance is too high, then hot spots can develop during normal operation that can damage the contacts.
- **Timing:** measures the speed at which the contacts close/ the circuit breaker operates. Slow operation means that during a fault more energy can be transmitted prior to interruption, or when closing arcing may occur and damage the contacts.

These tests are recorded and tracked over time and are used to measure the health of the transformer fleet. When circuit breakers fail these tests, corrective maintenance is carried out to bring them back into satisfactory working order. Frequent failures of test of a specific asset or type of assets can indicate that the asset(s) is approaching the end of its serviceable life and may need to be replaced.

As shown in the following charts, specific asset types have a high frequency of failure. Only assets types with failures are shown. Any with zero failures recorded against them are not shown in the charts.

[1] QDOC2010/37 Power Networks Asset Strategies Procedure, Revision 4

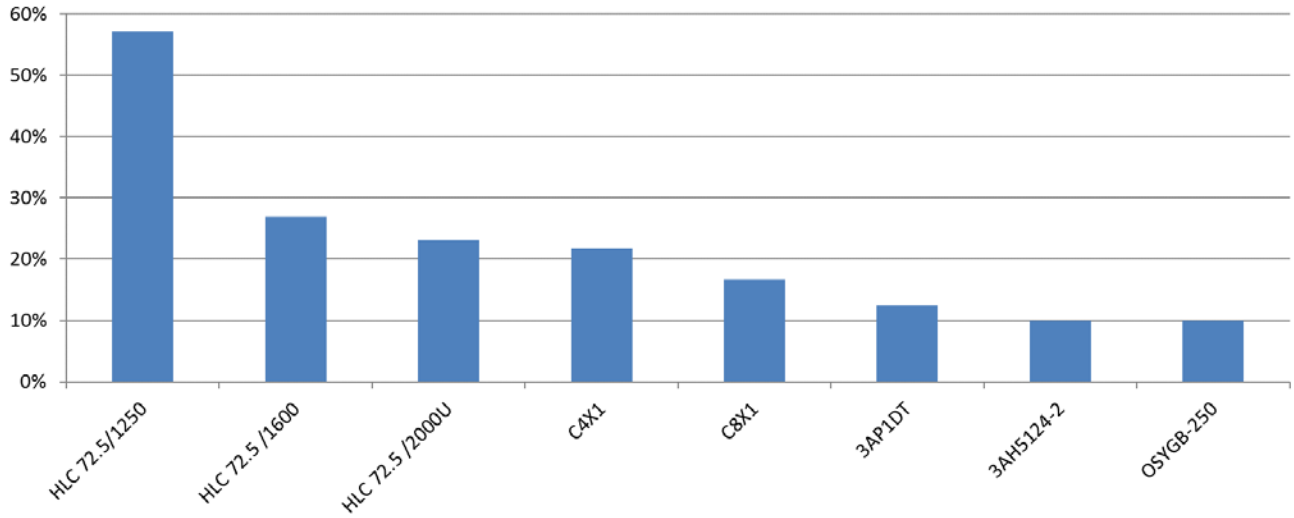

Figure 5-1 Insulation resistance test failures

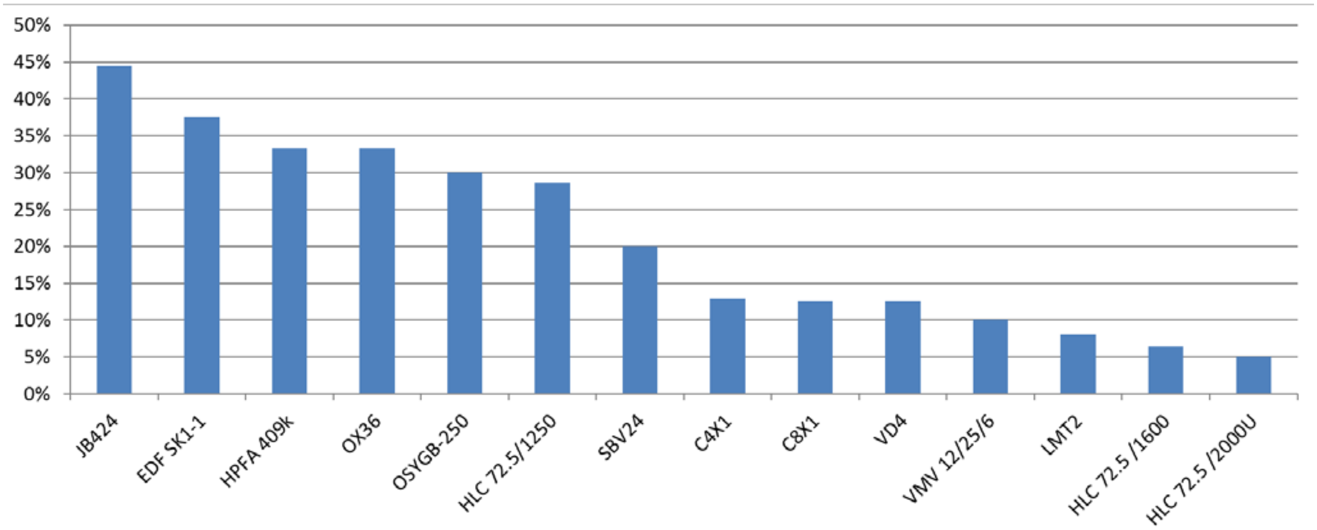

Figure 5-2 Contact resistance test failures

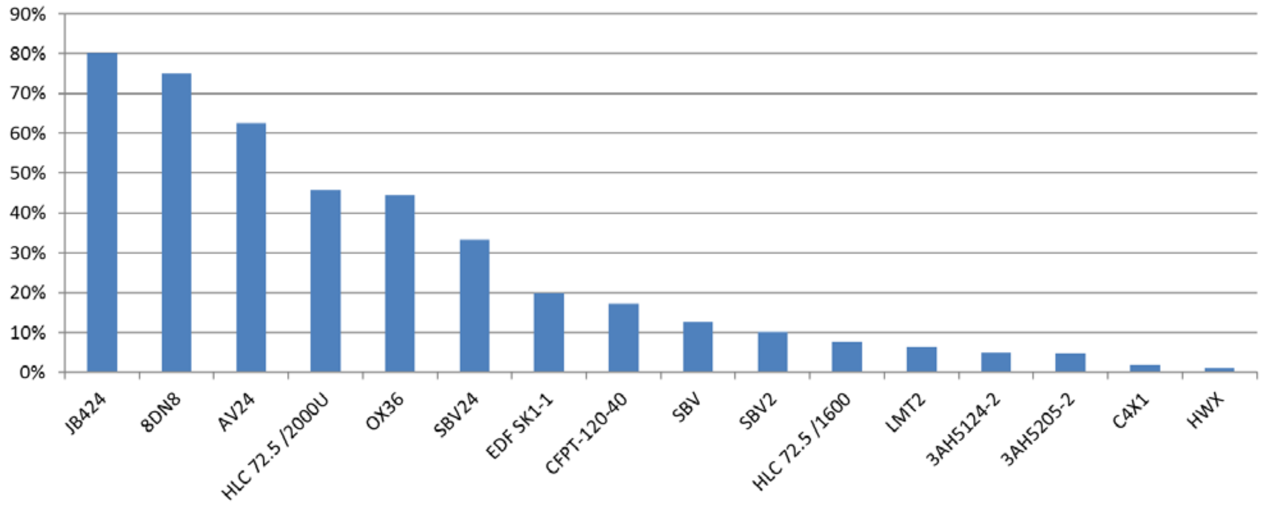

Figure 5-3 Timing test failures

These charts show a high number of failures for a number of assets, however, generally they can be fixed and returned to service through corrective maintenance. The cost of repairs and returning assets to service is recorded and is an input into assessing the asset health and need for replacement.

The asset health assessment is used to identify which assets pose a risk to the network and may require replacement, either individually or as a type replacement program.

5.1.2 Asset health assessment

Power and Water undertakes an asset fleet health assessment at portfolio level, to understand the risk posed to the network and to help identify where effort should be focused to effectively manage risk at the lowest cost to customers.

The asset health assessment is based on modelling the condition of circuit breakers using a combination of weighted attributes. Each attribute is allocated a score depending on defined performance criteria and it is then weighted to reflect its relative impact on health compared to the other attributes, refer to Table 5.1. The final result is an Asset Health score as follows:

- H1 – Good
- H2 – Average
- H3 – Poor

The weightings used to obtain the health score are shown in Table 14. If the Asset Score is H3, a further detailed investigation is undertaken.

Attribute	Weighting
Age (years)	20%
History of functional test failures for the asset and type	50%
Number of defects over the past 5 years	5%
Defect rectification cost over the past 5 years	10%
Insulation type	10%
Operating mechanism type	5%

Table 5.1 Asset health weighting criteria

Outcome

Table 5.2 shows the output of the health assessment.

Table 5.2 Health Score Results

Health Score	Health	Number of substations/switching stations	Number of circuit breakers
H1	**Good**	32	476
H2	**Average**	15	36
H3	**Bad**	12	58

Note: there substations may be counted multiple times if they contain circuit breakers of different health status. Spare circuit breakers and those associated with the Nomad transformers are not included in the table.

Table 5.2 shows that the 58 circuit breakers are distributed across a number of locations. Of these circuit breakers, 30 are HLC type that are identified to have a type issue, and the remainder are between 47 and 54 years old "bulk oil" type insulated circuit breakers spread across 5 substations and switching station.

5.2 Criticality

The criticality of a circuit breaker is an assessment of its importance to the continued operation, reliability, stability and security of the power network. Criticality is dependent on the following key attributes which are assessed at the level of a zone substation:

- The type of customer they serve, typically broken down into:
  - CBD, Urban and Rural for reliability metrics, and
  - Residential, Industrial and Commercial for the value of lost load (VoLL) or Value of Customer Reliability (VCR)
- Redundancy in the network, ie, the ability to re-establish supply from another feeder
- Amount of time required to replace the circuit breaker
- The voltage level of the circuit breaker

These characteristics have been assessed, using the criticality ranking of transformers, overhead lines and cables as a starting point. The results are shown in Table 5.3.

Table 5.3 Criticality ranking of substations

Criticality Rank	Criticality	Number of substations/switching stations	Number of circuit breakers
C1	Low	36	520
C2	Moderate	7	12
C3	Critical	4	38

Note: there substations may be counted multiple times if they contain transformers of different health status. Spare transformers and the Nomad transformers are not included in the table.

34 of the 38 critical circuit breakers are located at Hudson Creek and Channel Island. This is a logical result as approximately 90% of the electricity supplied to the Darwin Region comes via these two substations.

Out of these, three are HLC type circuit breakers.

5.3 Network risk

Network risk is the combination of the health and criticality of the circuit breaker. It is shown below in a risk matrix style format.

The health and criticality rankings for each circuit breaker are combined and shown in Table 5.4 as a qualitative overview using a risk matrix approach. This identifies there are 6 circuit breakers on the network with high risk and 3 with extreme risk.

All nine high risk circuit breakers are HLC type located at Hudson Creek.

Table 5.4 Current circuit breaker risk matrix

	H1	H2	H3
C1	435	36	49
C2	6	0	6
C3	35	0	3

Risk legend				
Very low	Low	Moderate	High	Extreme

Key challenges

This section summarises the current and emerging challenges faced by Power and Water. The section focuses on issues that are driving expenditure that are unique to Power and Waters network and environmental condition. Normal deterioration of assets is considered as business as usual and not discussed in this section.

The challenges are broken into categories of Environmental, Operational, Asset Challenges and Asset Management Challenges.

5.4 Environmental challenges

The network covers a range of environments and geographies which present various challenges for the HV circuit breaker asset class. Table 6.1 summarises the four operating regions covered by the network, setting out the type of environment, unique challenges in that environment and the implications.

Table 6.5: Environmental challenges in relation to HV circuit breaker asset management

Region	Environment	Challenges	Expenditure / risk implications
Alice Springs	Desert	• Extreme temperature changes both high and low • Limited time periods available for testing and maintenance due to the load profile • Remoteness	• Heat related stresses and reduced productivity resulting in increased time to undertake maintenance and inspection tasks • Suitably qualified and experienced resources are limited or non-existent and must be brought in from Darwin or interstate. This results in higher opex costs due to travel costs and time • Equipment and plant must be mobilised from Darwin for even minor defects • Provision of adequate cooling • Difficulty of conducting some tests in high temperatures (Dirana, DLA, IR)
Tenant Creek	Desert	• as above	• as above

Darwin	Coastal / Tropical	• Corrosion of external tanks
		• High rain fall and humidity resulting in:
		  ◦ Land contamination from oil leaks escaping from bunding and/or oil water separation treatment
		  ◦ High moisture content of circuit breaker insulating oil, increasing the rate of deterioration and reducing insulation properties
		• High temperatures contributing to increased deterioration rate of circuit breakers
		• Access to substations and being able to work on assets during the wet season – heat and rain/flooding (safety issue and detrimental to assets)
			• Higher oil testing and filtering requirements
			• Increased importance of maintenance to address leaks
			• Upgrading/maintaining integrity of bunding
			• Loss of insulation resulting in arcing
			• Deterioration of internal components (water/heat)
			• Oil contamination of surrounding land

Katherine	Desert / Tropical	• as above	• as above

5.5 Operational challenges

HLC type circuit breakers

The key operational challenge in managing HV circuit breakers has been the high maintenance requirements of the fleet of 66 kV ASEA HLC type outdoor circuit breakers. These circuit breakers have suffered an increasing range of problems as they approached the end of their economic lives such as:

- **Water in oil** – the HLC CB is a "free-breathing" design, so in the humid and wet environment of the Northern Territory, moisture enters the circuit breaker to the extent that significant volumes of 'free' water (i.e. water below the oil) must be drained from the circuit breaker stacks at each maintenance outage. Whilst the volumes of oil being drained are not measured, maintenance staff report several litres being drained from each stack at each outage. The presence of free water considerably increases the risk of the CB failing to break fault currents when required.
  Recent outage reports indicate that the water-in-oil problem is increasing (larger volumes of oil being drained), and that more frequent maintenance outages than the present biennial regime are advisable.
- **Contaminated insulators** – extreme environmental conditions result in greater surface contamination of the insulators than is advisable, resulting in an increased risk of tracking along the insulator surface.
- **Cracked insulating rods** – Power and Water believes that a batch of non-OEM insulating rods was procured at some time in the past, which wear more quickly and tend to develop cracks more easily than OEM components, resulting in replacement rods being required more frequently than expected.

Replacement of all HLC type circuit breakers is the subject of an asset-specific BNI and future business case recommending capital expenditure of $1.04m between 2019 and 2022.

Operational effectiveness of field crews due to heat and humidity

Power and Water operates in hot and humid environments. The environments are not comparable to other networks around Australia and have a significant impact on the productivity of the field crews. To assess and quantify the impact of the climatic conditions, Power and Water undertook a study[2] in selected locations across Australia.

Workability is the term used describe the productivity impact of climate in both Northern and Southern regions. It is the percentage of time for which work of different physical exertion can be effectively undertaken.

Table 6.2 describes the work rates used in the study along with a description and examples.

Table 6.6 Work rate descriptions

Work rate	Description	Work examples
Rest	Rest	Lunch and Crib Breaks
Low	Sitting with light manual hand/arm work. Driving. Standing with light arm work, occasional walking.	Driving, work planning, briefings and toolbox meetings, inspections
Moderate	Sustained moderate hand to arm work, moderate arm and truck work. Light pushing and pulling. Normal walking.	unpacking tools, spare parts, dismantle/ replace small electronic components, general switching from ground
High	Intense arm and truck work, carrying, shovelling, manual sawing, pushing and pulling heavy loads, walking at a fast pace.	Climbing ladders, working in trenches and cabinets, remove replace larger components
Very High	Very intense activity at fast to maximum pace.	Carrying larger tools and replacement components, lifting, carrying up ladders, digging

[2] Labour Efficiency and Work Management in Hot Humid Climates, Thermal Hyperformance.

		trenches, hauling cables, moving cable, pillars, poles

The outcome of the study is shown in Table 6.3 with the impact on Power and Water highlighted in orange. It demonstrates that the climatic conditions, particularly in Darwin where the majority of Power and Water's network is located, result in an average Workability of 65% compared to other major cities in Australia. This would equate to a 35% escalation of labour hours compared with the southern states for similar work and therefore an escalation of opex.

This is supported by feedback received via a heat stress survey which identified that approximately 50% of workers report daily or weekly heat-related impacts on their productivity.

Table 6.7 Workability for selected Australian locations based upon moderate metabolic rate

Location	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
Alice Springs	94%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Adelaide	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Brisbane	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Darwin	41%	44%	45%	60%	100%	100%	100%	100%	74%	46%	34%	32%
Hobart	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Melbourne	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Perth	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Sydney	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

5.6 Asset challenges

Other current and emerging challenges related to Power and Water's HV circuit breaker assets are noted below.

5.6.1 SF_6 circuit breakers

Power and Water operates a total of 120 circuit breakers that use SF_6 as the interrupting medium. An increasing number of these circuit breakers require frequent top-ups of SF_6 gas at each maintenance outage. For the 66 kV ABB EDF SK-1 type of circuit breaker (three in the fleet), top-up quantities amount to 1 kg at each outage; for the 132 kV Hitachi CFPT type (22 in the fleet), recent top-ups have amounted to 3-4 kg. Apart from the cost of the replacement gas, loss of SF_6 of these amounts is a concern owing to its high global warming potential as a greenhouse gas of 23,900 times that of CO_2.

5.6.2 GEC Switchgear 22 kV OX36 circuit breakers (three in fleet)

The three OX36 circuit breakers are SF_6-insulated circuit breakers equipped with vacuum interrupters. They are now more than thirty years old and are exhibiting age-related issues such as worn operating mechanisms leading to mechanical failures to operate correctly, SF_6 pressure switch faults, and cracked sight glasses in the housings. Owing to recent retirements of this type of circuit breaker in other locations, there are several poles available for use as spares; however, the remaining circuit breakers will require frequent maintenance until such time as they are replaced.

5.6.3 Hitachi 66 kV OSYGB circuit breakers (three in fleet)

The Hitachi 66 kV oil circuit breakers exhibit a range of age-related issues such as: cracks in the bushing sight glasses; air leaks in the compressed air system and operating mechanisms; slow operating times.

5.6.4 ABB 132 kV PASS MO circuit breakers

The ABB PASS MO SF_6 circuit breaker installations are extremely difficult to maintain, and do not appear to have been designed with operation and maintenance requirements in mind. It is not possible to physically test the circuit breaker in situ, so it is concerned that developing major problems due to the harsh operating conditions will not be identified in advance of them actually occurring.

6 Performance indicators

Circuit breakers are managed to ensure reliable, safe and sustainable distribution of electricity. To achieve these objectives, performance indicators will be established based on key risks and performance requirements. These indicators will be monitored and asset management strategies and plans are adjusted on a periodic basis to ensure the targets are met.

The key performance indicators will be aligned to the objectives set out in **Error! Reference source not found.** to ensure the management of circuit breakers will enable Power and Water to meet their overall network and corporate objectives.

This section of the asset management plan will set out the targets, actual performance and any gaps in the performance against the metrics. This will enable Power and Water to identify short comings in the asset fleet and develop or amend strategies and projects to close the gap.

While the performance indicators are currently under development, they are expected to cover the following general aspects:

- Circuit breaker availability
- Contribution to network reliability
- Circuit breaker condition, such as the number in poor health and outcomes of functional testing
- Environmental requirements such as oil contaminants and leaks
- Safety obligations, and
- Financial metrics to ensure efficient expenditure

These performance indicators will be developed and included in the next revision of this asset management plan.

7 Growth requirements

Power and Water plans their network to provide safe and reliable supply of electricity to customers. To achieve this, with respect to circuit breakers, key inputs to the network augmentation planning process include:

- Requirements set out in the Technical Code

- Forecast load growth
- Other augmentation projects

Forecast load growth

In 2017, Power and Water engaged AEMO to undertake a demand growth forecast for the network areas. The study outcome identified that there is one region of significant growth, four of low growth and demand for the remainder of the network is forecast to decline. The growth areas are summarised in Table 8.1.

Table 8.1 Zone substations with forecast growth (Summer, 10% PoE, FY18 to FY27)

Zone Substation	Region	Annual growth rate
Wishart ZSS (66/11 kV)	DRW	18%
Tennant Creek ZSS (11/22 kV)	TC	2.7%
Marrakai ZSS (66/22 kV)	DRW	2.5%
Archer ZSS (66/11 kV)	DRW	2%
Berrimah ZSS (66/11 kV)	DRW	2%

The two projects that are a result of the demand forecast are discussed below.

Other augmentation projects

Projects maybe initiated that result in the need to install additional circuit breakers on the network, for example, the establishment of a new zone substation or addition of an additional transformer at an existing substation.

7.1 Establish a new Wishart zone substation

Full details of the Wishart substation are available in the document D2017/394282.

7.1.1 Network constraints

There has been ongoing development in the East Arm and Wishart areas during the past 10 years. Augmentation of infrastructure has been deferred through the implementation of temporary solutions, including the deployment of the Nomad modular substation at Wishart, to allow better assessment of network growth. There are currently a number of confirmed new developments planned for the Berrimah, Wishart, and East Arm areas, which will add approximately 46 MVA to the network. This is supported by the 18% load growth by the end of FY27 forecast by AEMO[3].

7.1.2 Option considerations

Four options were considered:

1. Do nothing
2. Establishing a new Wishart Zone Substation
3. Install a third transformer at Berrimah
4. Implement demand management

[3] Australian Energy Market Operator, Power and Water Corporation maximum demand, energy consumption and connections forecast, September 2017

7.1.3 Growth plans

Of these options, studies have shown that option 2, establishing a new Wishart Zone Substation will most efficiently address the needs of the area. It will also make the Nomad modular substation available for redeployment to other sites, therefore improving the ability of Power and Water to react to future network constraints. The project will include installation of approximately 5 outdoor 66 kV circuit breakers and 18 indoor 11 kV circuit breakers, final numbers to be determined during detailed design.

Option 2 was preferred as it had the best strategic alignment and highest NPV.

7.2 Archer 3rd Transformer

Full details of the Archer 3rd transformer are available in the document D2017/394304. The currently preferred option to resolve a forecast capacity constraint at Archer ZSS is to deploy the Nomad modular substation. This will not result in any new circuit breakers being installed on the network.

7.3 Long term growth

The network demand forecast shows that the demand is expected to decline over the next 10 years. The four growth areas will be addressed within the forthcoming regulatory control period (FY19 to FY24). Once that demand growth is addressed, there is no need currently identified for additional circuit breakers to be installed on the network.

Network demand will be reviewed on an annual basis as required by the Technical Code. Should there be a change in the forecast, appropriate analysis will be undertaken to identify the most efficient approach to address the demand growth.

8 Renewal and maintenance requirements

Power and Water routinely assesses asset condition to determine the risk each circuit breaker poses to the network. The data is analysed to asset the risk of asset failure and the criticality of the asset.

When condition defects or risks are identified, options are assessed on how to most efficiently manage the risk. This may include operational measures such as repairing oil leaks, replacing components or refilling gas, thorough to capital investments to replace part or all of the circuit breaker. To identify the timing and scope of the preferred option, Power and Water undertakes a cost and benefit analysis and assessment of technical and economic benefits and risks, as required by the Technical Code.

Considerations may include:

- Condition of the circuit breaker and associated components
- Results of functional and electrical test
- Maintenance performance and expenditure history
- Cost of replacement of different options
- Calculating the present value of each option

- Environmental concerns

Power and Water takes a risk based approach to asset replacement. They do not 'buy out risk', instead they assess when it is economic to replace an asset based on the risk it presents (the product of consequence and likelihood).

The following sections provide an evaluation of renewal and maintenance requirements in relation to existing assets.

Section 9.1 below discusses projects that are currently in progress or will be completed by the end of the current regulatory period.

Section 9.2 to 9.7 below discuss projects that will be started and completed during the FY20 to FY24 regulatory period.

8.1 Projects currently in progress

8.1.1 Cosmo Howley

This project will replace the bulk oil, pneumatic 66 kV circuit breakers at the substation. The project will be completed during FY18.

8.1.2 Manton Dam

This project will replace 4 bulk oil, pneumatic 66 kV circuit breakers at the substation. The project will be completed during FY19 and is the final stage of a long term program to remove circuit breakers with pneumatic type mechanisms from the network.

8.1.3 Austin Knuckey and West Bennett switching stations

These projects will replace all the circuit breakers at both Austin Knuckey and West Bennet switching stations. Both of these stations contain 10 circuit breakers which have exceeded their expected serviceable lives and are allocated a health rating of H3. The proejct will be completed during FY18.

Austin Knuckey has 10 bulk oil indoor circuit breakers that are 47 years old and West Bennet has 10 10 bulk oil indoor circuit breakers that are 52 years old categorised as H3. They are failing their Insulation resistance test 22% of the time and Contact Resistance test 13% of the time.

8.1.4 Casuarina 66 kV switchyard replacement

This project will replace 10 outdoor 66 kV circuit breakers at the substation. The project will be completed during FY18.

8.1.5 Pine creek 66 kV switchyard replacement

Pine Creek is comprised of a 132kV step up transformer connected to a generator and a separate 66kV/22kV switchyard.

The 66kV switchyard includes two 20MVA transformers and supply a forecast maximum demand of 43.46 MVA from FY18 through o FY24. The transformers require replacement based on condition. The circuit breakers at Pine Creek have an average age of 38 years. This project will replace all of the 66 kV and the remaining single 22 kV circuit breakers and develop a new meshed switchyard.

The project will be completed by the end of FY19.

8.2 66 kV ASEA HLC circuit breakers

Full details of this project are available in the document wit hTRIMD2017/364601.

8.2.1 Overview

Power and Water owns and maintains 30 66 kV ASEA HLC outdoor oil circuit breakers that were originally installed in the aftermath of Cyclone Tracy.

As discussed in section 0, the HLC circuit breakers have an identified type issue that is affecting the entire fleet. This has resulted in a higher frequency of outages, poor performance in functional tests and higher cost for maintaining the assets.

Repeated operation and maintenance problems with this type of circuit breaker in the tropical environment of the Northern Territory has prompted the progressive replacement of these circuit breakers. The programme will be completed during the 2019/24 regulatory control period with the replacement of the 16 circuit breakers located in Hudson Creek and Palmerston Zone Substations.

8.2.2 Options considered

There are three potential solutions, including the ‘do nothing’ business-as-usual outcome.

- **Business-as-usual** – continue to maintain and repair the 16 HLC circuit breakers remaining at the end of 2016/17.
- **Replace on failure** - continue to maintain the 16 HLC circuit breakers remaining at the end of 2016/17 for the remainder of their service lives. Replace any irreparable failures with similar modern equivalents. Statistically, it is not realistic to expect that all existing CBs will continue to operate to the end of the 2019-2024 regulatory control period without significant repairs being required.
- **Planned replacement project** – plan to replace the HLC CBs on a substation by substation basis. Prioritise replacement of the older CBs at Palmerston before the younger CBs at Hudson Creek. Replace Hudson Creek CBs over two consecutive years to reduce impact on contractor and Power and Water resources.

8.2.3 Plan

The preferred option is to undertake a planned replacement project during the forthcoming regulatory control period. The planned replacement option is more efficient and also allows the business to plan the replacement programme to suit other business needs, rather than waiting for CBs actually to fail. Table 9.1 shows the planned schedule of replacements of these assets.

Table 9.1: HLC circuit breaker renewals 2017/18 to 2023/24

Voltage kV	Replacement volumes						
	2017/18	2018/19	2019/20	2020/21	2021/22	2022/23	2023/24
66 kV HLC	7	7	5	6	5		

8.3 Berrimah

Full details of this project are available in the document D2017/394263 PRD30402 - Preliminary Business Case PBC - Replace Berrimah Zone Substation.

8.3.1 Overview

The Berrimah Zone Substation was commissioned in 1981. It comprises a 66kV outdoor air insulated 66kV switchyard, two 66/11kV 25/31.5/38MVA power transformers, and an 11kV indoor metalclad switchboard and associated secondary systems. The site was also a connection point for 2 x 10 MW gas turbines, decommissioned in 2010/11.

66kV Switchgear

The 66kV switchyard consists of 5 x ASEA HLC minimum oil circuit breakers that were manufactured in 1980 – they are currently 37 years old and identified to have a type issue. The sixth circuit breaker was installed in 2002 to replace the ASEA HLC circuit breaker that previously failed in service.

22kV Switchboard

The 11kV switchboard was commissioned with bulk oil circuit breakers but was subsequently retrofitted with vacuum circuit breakers in 2009 following the explosive failure at Casuarina Zone Substation that involved a similar type of bulk oil circuit breakers. While the vacuum breakers are an improvement in safety, operations have been impacted by the retrofit as the full functionality and features of the original switchboard have been compromised. There are a number of other safety concerns:

- the switchboard itself is not arc-fault contained (unlike modern switchgear) and there is a growing concern for the safety of operational staff working in and around this equipment.
- the original frame leakage bus protection for the switchboard is no longer operational, due to failure of the insulating medium, which increases the energy involved with bus faults and arc flash incidents as the switchboard fault clearance relies on slower operating backup protection.

Reducing the safety risk to operational staff from the inadequate arc containment risk requires replacement of the switchboard. In the interim, operational instructions restrict the time staff spend in the switch room to a practical minimum.

8.3.2 Option Considerations

There were seven options considered to resolve the issues at Berrimah ZSS:

1. Do nothing (continue to maintain/repair Berrimah ZSS)
2. In situ [‘brownfields’] renewal of the existing Berrimah ZSS with non-standard 38.1MVA 66/11kV Transformers
3. In situ [‘brownfields’] renewal of the existing Berrimah ZSS with non-standard 50MVA 66/11kV Transformers
4. In situ [‘brownfields’] renewal of the existing Berrimah ZSS with non-standard 50MVA 66/11kV Transformers
5. Construct a new air insulated switchgear (AIS) Berrimah Zone Substation
6. Construct a new gas insulated switchgear (GIS) Berrimah Zone Substation
7. Demand Management

8.3.3 Plan

The preferred option is Option 5, to construct a new zone substation. This is due to the risks and high cost of undertaking brownfield replacement works while ensuring the zone substation remains in service.

Additional benefits include:

- Using standard equipment and layout
- Lower cost
- Allows for the future expansion of the substation when demand requires the installation of a third transformer.

This will result in the replacement of 23 circuit breakers in total.

8.4 Humpty Doo

Full details of this project are available in the document D2017/394662 394662 PRD30401 - Preliminary Business Case PRC - Replace Humpty Doo ZSS.

8.4.1 Overview

Humpty Doo is a 66/22 kV rural substation in the Darwin-Katherine network. It consists of two 2.5 MVA transformers and two 22 kV circuit breakers that feed the distribution area. Both transformers are in poor condition and require replacement. The three circuit breakers are outdoor oil type and currently range in condition from H1 to H3. The will all be over 40 year old at the expected time of replacement.

All aspects of the substation have been identified as being at end of life. There are no capacity issues identified.

8.4.2 Option Considerations

Three options were identified to remediate the issues:

1. Do nothing
2. Replace the existing switchyard on a like for like basis
3. Install a new AIS 66/22kV zone substation and decommission the existing Humpty Doo ZSS

4. Demand management

8.4.3 Plan

Initial assessment has indicated that Option 3 is the most efficient approach to resolve the issues. Deployment of the Nomad modular substation will enable efficient decommissioning and re-establishment of Humpty Doo without affecting customer supply.

8.5 Centre Yard

Full details of this project are available in the document D2017/394625 PRD33125 - Preliminary Business Case PBC - Darwin - Replace Centre Yard Zone Substation.

8.5.1 Overview

Centre Yard Zone Substation is located in Cox Peninsula and consists of two 0.5MVA 66/11kV transformers connected to a single 66kV ASEA HLC minimum oil circuit breaker. The substation is fed from Darwin Zone Substation by two 66kV undersea cables of approximately 8km in length, each with sections of 66kV overhead line at each end.

The local distribution network operates at 22 kV and is supplied from Strangways Zone Substation.

Both of the subsea cables have experienced failures and one is permanently out of service as it was not economical to repair.

All assets in the zone substation are in poor condition. There are no capacity constraints identified.

8.5.2 Option Considerations

Five options were identified to remediate the issues:

1. Do nothing
2. Refurbish the existing substation
3. Construct a new 66/11 kV AIS ZSS to replace the existing substation
4. Construct a new 66/22 kV micro substation and convert the distribution area to 22 kV
5. Convert the 11kV distribution network to 22kV, supply the network from Strangways ZSS and decommission the substation
6. Demand management.

8.5.3 Plan

Option 4 is the preferred option. The existing 66 kV circuit breakers will be decommissioned and replaced by a single new 66 kV circuit breaker. The project is expected to be implemented by FY22.

8.6 Random asset failure

This section outlines the expected replacement needs for random failures.

8.6.1 Overview

The population is broken down by manufacturer, model and type in Appendix B – Asset data.

11 kV circuit breakers

There are no significant ongoing or emerging issues with the 11 kV circuit breaker fleet. The average age is only 16.8 years, and the 278 circuit breakers have an estimated average remaining life of about 28.5 years. There are currently 20 circuit breakers that are older than the estimated economic life of 45 years, however, these all located at Austin Knuckey and West Bennett switching stations and will be replaced during FY18.

22kV circuit breakers

Most of the 22 kV fleet are quite recent Siemens units, such that the total 22 kV fleet's average age is only 15.6 years, with an estimated average remaining life of about 29.4 years. None of the units are older than the estimated average economic life of 45 years. The 42 Siemens units have an average age of only 8.7 years, with an estimated average remaining life of 36.3 years.

66 kV circuit breakers

The 66 kV circuit breaker fleet, excluding the HLC and Hitachi units, mostly comprises Siemens units less than 10 years old with an average age of 7.2 years. Asa result there are no significant issues expected to emerge, other than the already identified type issues.

132 kV circuit breakers

8.6.2 Plan

Overall, excluding the assets planned for replacement as part of the projects mentioned in sections 9.2 to 9.5, the circuit breaker fleet is in good condition and can be managed through maintenance. There is no expectation for any major failures up to the end of the next regulatory period.

11 kV Plan

Owing to the overall quantity of 11 kV circuit breakers, it is to be expected statistically that a few will require replacement each year. However, given the asset fleet is very young and the remaining assets that are beyond their expected life and in poor condition will be replaced by the end of FY18, there is a very low risk of asset failure. Therefore, Power and Water plans to manage the risk through maintenance and the use of spares.

22 kV Asset management plan

There are some minor issues with the existing older 22 kV switchgear, which are planned to be managed using the existing procedures and spares inventory.

Owing to the overall number of 22 kV circuit breakers (73), and the high proportion of Siemens units, most of which are less than 10 years old, the fleet is in overall good condition. Repex modelling suggests that only one 22 kV circuit breaker will likely require replacement during the 2019-2024 regulatory control period, however, the network risk of these circuit breakers are generally low to moderate and Power and Water plans to manage this risk through maintenance and use of spares if required.

The following circuit breaker types will be managed through use of spare components to extend their serviceable lives:

- Yorkshire Switchgear YSF6 units have had problems with flashovers in the cable chutes. Older units at Manton and Katherine ZSSs were replaced about 8-10 years ago with Siemens units, which provided a pool of spare components to be used in the repair of more recent failures.
- The three GEC Switchgear OX36 circuit breakers are SF_6-insulated circuit breakers equipped with vacuum interrupters. They are now more than thirty years old and are exhibiting age-related issues such as worn operating mechanisms leading to mechanical failures to operate correctly, SF_6 pressure switch faults, and cracked sight glasses in the housings. Owing to recent retirements of this type of circuit breaker in other locations, there are several poles available for use as spares; however, the remaining circuit breakers will require frequent maintenance until they are replaced.

66 kV Asset management plan

The asset replacement programme for the remaining ASEA HLC circuit breakers is described in detail in section 9.2.

Apart from a risk that Hitachi OSYGB circuit breakers might require replacement, and barring completely unexpected catastrophic failure, the high proportion of Siemens units under 10 years of age means that it is extremely unlikely that any other 66 kV circuit breakers will require replacement until approximately 2030.

132 kV Asset management plan

Four existing 132 kV circuit breakers will be replaced in FY19 at Manton Dam substation. This is the final stage of long term programme and will remove the last of these pneumatic type circuit breakers from the network.

Apart from the risk posed by the ABB PASS MO SF_6 circuit breakers due to limited inspection and maintenance that can be carried out while in situ, the 132 kV circuit breaker fleet has a relatively young average age and no assets are expected to exceed their deign life prior to FY24.

8.7 Long-term (8-12 years) renewal needs

The condition of circuit breakers will be regularly assessed and the latest results used to inform future risk mitigation needs. When a circuit breaker is expected to require replacement, a full range of options is assessed to ensure future demand and customer needs are considered.

Power and Water will also aim to align circuit breaker replacements with other major capital works such as transformer and protection relay replacements.

At the end of the next regulatory period, the majority of the high risk circuit breakers will have been replaced and the fleet is expected to be in a good condition. Currently, there is no forecast for replacements beyond FY24.

9 Investment program

The investment program is developed based on the:

- Continuation of the established lifecycle asset management approaches
- Specific requirements related to growth in the asset class – outlined in Section 8; and
- Specific requirements related to renewal and maintenance of the asset class – outlined in Section 9.

9.1 Augmentation expenditure (augex)

The augmentation expenditure below is the component related to HV circuit breakers only.

Table 10.1: Circuit breaker augmentation quantities forecast

Project/Program	FY18	FY19	FY20	FY21	FY22	FY23	FY24	Total
Construct Wishart Zone Substation (66 kV)							5	**5**
Construct Wishart Zone Substation (11 kV)							18	**18**
Total quantities							23	23

Table 10.2: Circuit Breaker augmentation expenditure forecast ($’000, real FY18)

Project/Program	FY18	FY19	FY20	FY21	FY22	FY23	FY24	Total
Construct Wishart Zone Substation (66 kV)					$1,151.0	$1,278.8	$1,122.2	$3,552.0
Construct Wishart Zone Substation (11 kV)					$499.3	$554.8	$486.9	$1,541.0
Total repex					$1,650.3	$1,833.7	$1,609.0	$5,093.0

9.2 Renewal expenditure (repex)

The renewals expenditure below is the component related to HV circuit breakers only.

Table 10.3: Circuit breaker replacement quantities forecast

Project/Program	FY18	FY19	FY20	FY21	FY22	FY23	FY24	Total
ASEA 66kV HLC Circuit Breaker Replacement	-	-	5	6	5	-	-	16
Replace Casuarina ZSS 66kV Outdoor Switchyard	10	-	-	-	-	-	-	10
Replace Humpty Doo ZSS - Switchgear (66kV)	-	-	-	-	-	1	-	1
Replace Humpty Doo ZSS - Switchgear (22kV)	-	-	-	-	-	2	-	2
Replace Berrimah ZSS - Switchgear (66kV)	-	-	-	6	-	-	-	6
Replace Berrimah ZSS - Switchgear (11kV)	-	-	-	17	-	-	-	17
Replace 66/11kV Centre Yard ZSS - Switchgear (66kV)	-	-	-	-	1	-	-	1
Replace Pine Creek - Switchgear (66kV)	-	4	-	-	-	-	-	4
Replace Cosmo Howley - Switchgear (66kV)	1	-	-	-	-	-	-	1
Replace 4 x 132kV CB at Manton Dam	-	4	-	-	-	-	-	4
Replace Tennant Creek 22kV indoor switchboard	-	-	-	-	-	-	-	-
Total quantities	11	8	5	29	6	3	-	62

Table 10.4: Circuit breaker replacement expenditure forecast ($'000, real FY18)

Project/Program	FY18	FY19	FY20	FY21	FY22	FY23	FY24	Total
ASEA 66kV HLC Circuit Breaker Replacement	$-	$-	$325.0	$390.0	$325.0	$-	$-	$1,040
Replace Casuarina ZSS 66kV Outdoor Switchyard*	$131.1	$-	$-	$-	$-	$-	$-	$131
Replace Humpty Doo ZSS - Switchgear (66kV)	$-	$-	$-	$-	$314.3	$244.2	$-	$558
Replace Humpty Doo ZSS - Switchgear (22kV)	$-	$-	$-	$-	$381.0	$296.1	$-	$677
Replace Berrimah ZSS - Switchgear (66kV)	$200.0	$675.0	$579.0	$510.0	$-	$-	$-	$1,964
Replace Berrimah ZSS - Switchgear (11kV)	$100.0	$839.0	$720.0	$633.0	$-	$-	$-	$2,292
Replace 66/11kV Centre Yard ZSS - Switchgear (66kV)	$-	$-	$-	$-	$165.0	$-	$-	$165
Replace Pine Creek - Switchgear (66kV)	$238.1	$751.6	$-	$-	$-	$-	$-	$990
Replace Cosmo Howley - Switchgear (66kV)*	$130.0	$-	$-	$-	$-	$-	$-	$130
Replace 4 x 132kV CB at Manton Dam	$-	$500.0	$-	$-	$-	$-	$-	$500
Replace Tennant Creek 22kV indoor switchboard*	$120.0	$-	$-	$-	$-	$-	$-	$120
Total Repex	$919.1	$2,765.6	$1,624.0	$1,533.0	$1,185.3	$540.3	$-	$8,567

*Project partially complete and costs do not reflect total project value.

9.3 Operational expenditure (opex)

The historical operating expenditure and indicative forecast for HV circuit breakers for the next regulatory period is provided in Table 10.5.

Table 10.5: Operating expenditure forecast

Asset type	Expenditure category	FY14 (H)	FY15 (H)	FY16 (H)	FY17 (H)	FY18 (H)	FY19 (F)	FY20 (F)	FY21 (F)	FY22 (F)	FY23 (F)	FY24 (F)
HV Circuit Breakers	Routine	$0.87	$1.05	$0.71	$0.84	$0.72	$0.66	$0.61	$0.61	$0.61	$0.61	$0.61
	Non-routine	$0.46	$0.59	$0.80	$0.58	$0.60	$0.54	$0.48	$0.48	$0.48	$0.48	$0.48
	Fault and emergency	$0.50	$0.15	$0.05	$0.20	$0.21	$0.20	$0.20	$0.20	$0.20	$0.20	$0.20
Total		**$1.83**	**$1.79**	**$1.56**	**$1.62**	**$1.52**	**$1.40**	**$1.28**	**$1.28**	**$1.28**	**$1.28**	**$1.28**

10 Asset class outcomes

This section is closely related to Section 7. Where Section 7 sets out the targets, current performance and any gaps in the performance against the metrics, this section will identify the expected performance against the metric once the projects identified in Sections 8 and 9 have been implement.

The success of the strategies and project will be measured against these targets and intended performance. This will enable Power and Water to identify short comings in the asset fleet and develop or amend strategies and projects in order to achieve the desired fleet performance.

While the performance indicators are currently under development, they are expected to cover the following general aspects:

- Circuit breaker availability
- Contribution to network reliability
- Circuit breaker condition, such as the number in poor health and outcomes of functional testing
- Environmental requirements such as oil contaminants and leaks
- Safety obligations, and
- Financial metrics to ensure efficient expenditure

These performance indicators will be developed and included in the next revision of this asset management plan.

10.1 Network risk

Network risk is an important outcome of the asset investment plan that Power and Water can currently forecast. The risk matrix was recalculated for the end of the regulatory period based on two scenarios: with investment and without investment. The results are shown in Table 11.1 and Table 11.2. The scenario with investment includes the addition of 23 new circuit breakers at Wishart ZSS and the decommissioning of 6 others for a net addition of 9 circuit breakers.

The tables show that without investment the risk profile of the network increases with more assets entering the H2 and H3 categories.

If investment is undertaken as planned, the network risk profile is expected to reduce so there will only be 1 circuit breaker with extreme risk on the network and the number of circuit breakers with high risk will reduce to three. In general, the number of circuit breakers in the H2 and H3 categories will decrease.

The investment plan will result in a more reliable and safe network that is achieved through appropriate management of network risk.

Table 11.1 Circuit breaker risk matrix without investment

	H1	H2	H3
C1	431	35	54
C2	6	0	6
C3	35	0	3

Table 11.2 Circuit breaker risk matrix with investment

	H1	H2	H3
C1	479	33	25
C2	9	0	3
C3	37	0	1

11 Performance monitoring and improvement

Ongoing condition and performance monitoring is a key part of Power and Water's performance evaluation and improvement strategy. Study of the condition and performance data captured over time assists in developing valuable insights on transformer defect modes and trends. These insights provide for informed decision making on whether to repair or replace assets. It assists in the continuous development of the asset management strategy for transformers.

11.1 Monitoring and improvement

This Asset Management Plan will be reviewed at least every two (2) years or when there is a significant driver from the network or other events that requires revision.

Improving data resources, undertaking data analysis and deriving insights will be undertaken as business as usual activities. Any improvements in analysis of the transformer fleet will be included in this AMP when it is updated.

The RACI in section 3.2 allocates the responsibility for each task in the management of transformers, including performance monitoring and strategy revision.

12 Appendix A – Lifecycle asset management

Power and Water make great efforts to be a customer oriented organisation that provides a safe, reliable and efficient electricity supply in the Northern Territory. This is demonstrated in the approach Power Networks take in managing its assets. The life cycle asset management approach applied by Power Networks is aimed at making prudent asset management decisions such that its assets do not cause harm to any person, have minimal environmental impact, and meet agreed service performance outcomes, consistent with current and future needs.

The approach includes:

- Maximising the utilisation of its assets throughout its life cycle
- Optimising life cycle asset management costs
- Reducing asset risks as low as reasonably practical
- Continually improving its knowledge in respect of its assets

The following asset management activities detail Power and Water's life cycle management of its HV circuit breaker assets.

12.1 Planning (augmentation)

The asset planning stage defines the need for an asset to exist. It also establishes the functional requirements of the assets and ultimately the number of assets, design, function, criticality, configuration, level of redundancy, capability, and capacity.

During the planning process, Power and Water must have regard to the Code. Part C of the Code sets out the Network Planning Criteria, including the following key clauses:

- Clause 13.8.1 sets out the requirement for Power and Water to undertake an annual planning review including to consider loads, generation and non-network solutions
- Clause 13.9 sets out the investment analysis and reporting requirements including the need to determine the least cost option on a present value basis and include in the analysis an estimate of system benefits and non-quantifiable economic benefits
- Clause 14 sets out the supply contingency (security) criteria which are summarised in Tables 13 and 14, including:
  - Specifying forecast demand is based on the coincident maximum demand with a 50% probability of exceedance
  - Restoration time targets for outages

An important outcome of these requirements is that an area with a forecast demand of over 50 MVA has a requirement to be restored within five hours for a second supply contingency. This requirement only applies to Hudson Creek as all other substations have demand of less than 50 MVA.

Key criteria to ensure establishment of prudent, cost efficient, intrinsically safe, and sustainable asset installations for the life cycle management of the circuit breaker assets include consideration of:

- Robust demand forecasting by zone substation
- Security requirements set out in the Code

- Optimised utilisation of existing assets
- Load transfers available on a permanent or temporary basis to defer investment and manage risk
- Non-network solutions
- Schedule and cost impacts from existing adjacent infrastructure
- Transport and logistics
- Project cost implications
- Safety and reliability risks
- Environmental and approvals risk
- Stakeholder and community requirements
- Design and execution requirements
- Operation and maintenance requirements

12.2 Design

The design phase is where decisions around the physical characteristics and functioning of the asset is made. This life cycle stage defines the quality and reliability of the asset, and the whole-of-life cycle costs that can be realised. It influences the total cost and the level of service that the assets can deliver to customers and shareholders.

Power and Water's approach to the whole-of-life prudent and efficient design of assets include the standardisation of zone substation designs as far as practicable given the broad range of capacities and locations. Standardisation is defined as the process of developing and agreeing uniform technical design criteria, specifications and processes and is a key aspect of Power and Water's asset management process.

Along with continuity, leverage and scalability, standardisation enables consistent application of best industry practise and continuous performance improvement. It establishes technical commonality that allows for an off-the-shelf, best practice, and fit-for-purpose approach to engineering solutions. It also allows for interchangeability that provides operations and asset management benefits.

Power and Water's zone substation design standardisation offers the following specific benefits to the business:

- helps with the ranking and prioritisation of investment projects
- gives confidence in the safe and reliable functioning of the assets
- provides assurance that the assets will do the job they were intended for
- boosts production and productivity
- encourages higher quality of engineering leveraging specialist knowledge and optimum solutions
- allows the uniform execution of projects
- enables standardisation of construction equipment and processes

12.3 Operation

Asset operations include activities associated with the monitoring, operation and control of the asset to adapt to changing requirements of the network, and includes:

- Planned switching of the network for scheduled works (e.g. maintenance)
- Emergency switching of the network in response to incidents (e.g. fault events)
- Real time switching to operate the asset within its design parameters (e.g. loading)
- Monitoring of the condition of the asset (e.g. alarms)
- Adjusting tap changer settings to regulate voltage levels

12.4 Maintenance (opex)

Asset maintenance involves the care of assets to ensure they will function to their required capability in a safe and reliable manner from their commissioning to their disposal. The maintenance requirements evolve as the condition and performance requirements of the assets change through its life. Power and Water monitors and provides feedback on asset condition, incorporates upkeep and repair activities to maintain the condition of the asset, and includes the monitoring and management of the deterioration of an asset over time. Three main types of maintenance activities are defined: preventative, corrective, and unplanned maintenance.

- **Preventative maintenance** involves the controlled care and repair activities carried out to reduce the probability of failure or degradation of asset performance. It includes routine inspection and testing, monitoring, upkeep and repair, and component replacement. Preventative maintenance expenditure increases over time as assets age as more frequent inspections and testing are planned.
- **Corrective maintenance** involves activities to repair asset defects identified as result of condition assessments or failures. Corrective maintenance expenditure increases over time as assets age and deteriorate, and more frequent intervention is required.
- **Unplanned maintenance** involves activities to immediately restore supply or make a site safe in response to unplanned failures. Unplanned maintenance expenditure increases over time as asset age and deteriorate.

Power and Water employs a biennial inspection and testing regime to assess the condition of HV circuit breaker assets. The inspection involves a judgement of condition and risk of failure based on a combination of visual assessment and testing of circuit breaker electrical and mechanical operating parameters with system performance tracking to provide a pointer to potential asset integrity issues. High-risk assets are prioritised for further investigation and testing.

Further details of maintenance tasks and frequency for each make and model of circuit breaker are detailed in the Power Networks Asset Strategies Procedure[4]. While strategies are typically based on interrupting medium, specific tasks for particular types are required to maintain acceptable condition.

[4] QDOC2010/37 Power Networks Asset Strategies Procedure, Revision 4

12.5 Renewal (repex)

Asset renewal is the establishment of new assets in response to existing assets' deteriorating condition. The need for the renewal of existing assets is identified in the asset maintenance stage and verified in the asset planning stage. Asset renewal aims to optimise the utilisation of an asset whilst managing the safety and reliability risk associated with the failure of the asset.

Power and Water has asset replacement programmes in place to renew assets of poor condition as close as possible yet prior to the asset failing.

- Replace
- Refurbish
- Relocate

The network risk posed by circuit breaker failure is assessed on a qualitative basis using the condition data and risk assessment framework and on quantitative basis using energy at risk. These two approaches enable Power and Water to identify assets in poor condition, prioritise the replacements and determine the optimal timing of replacement.

When replacing major assets such as circuit breakers, Power and Water aims to align other related major works to gain efficiencies.

12.6 Disposal

The decision to reuse or dispose of an asset is made with consideration of the potential to:

- reuse the asset
- use the asset as an emergency spare
- salvage asset components as strategic spare parts.

Remaining assets are disposed of in an environmentally responsible manner and in compliance with all requirements related to scheduled materials and substances (e.g., insulating oils and gases, PCBs, etc.).

13 Appendix B – Asset data

13.1 CB volumes by location and voltage

Table 14.1: HV circuit breaker volumes by location and voltage level

REGION	LOCATION	VOLTAGE LEVEL			
		11	22	66	132
ALICE SPRINGS	LOVEGROVE ZSS	17	11	5	
ALICE SPRINGS	OWEN SPRINGS			5	
ALICE SPRINGS	SADADEEN ZSS (RON GOODIN 11KV)		14		
DARWIN	AUSTIN KNUCKEY SS	10			
DARWIN	ARCHER ZSS	18		8	
DARWIN	BATCHELOR ZSS		6		1
DARWIN	BERRIMAH ZSS	22		6	
DARWIN	CASUARINA ZSS	29		6	
DARWIN	COSMO HOWLEY ZSS			1	
DARWIN	CHANNEL ISLAND				25
DARWIN	COX PENINSULA			1	
DARWIN	DARWIN ZSS	26		10	
DARWIN	FRANCES BAY ZSS	21		6	
DARWIN	HUDSON CREEK			13	6
DARWIN	HUMPTY DOO ZSS		2	1	
DARWIN	JABIRU	7			
DARWIN	LEANYER ZSS	18		5	
DARWIN	MARRAKAI ZSS			1	
DARWIN	MITCHELL STREET SS	9			
DARWIN	MANTON ZSS		9		4
DARWIN	PALMERSTON ZSS	31		5	
DARWIN	WEST BENNET SS	10			
DARWIN	WEDDELL ZSS			9	
DARWIN	WISHART MODULAR SS	8		1	
DARWIN	WOOLNER ZSS	27		12	
DARWIN	WOODS STREET SS	13			
DARWIN	XC	7			
KATHERINE	KATHERINE ZSS		22		2
KATHERINE	PINE CREEK ZSS		1	3	
KATHERINE	PINE CREEK			1	1
KATHERINE	TINDAL ZSS	5	8		

REGION	LOCATION	VOLTAGE LEVEL 11	22	66	132

13.2 Age profiles

Power and Water's HV circuit breaker fleet dates from newly installed to the oldest that were installed in FY 1965/66, a range of more than 50 years.

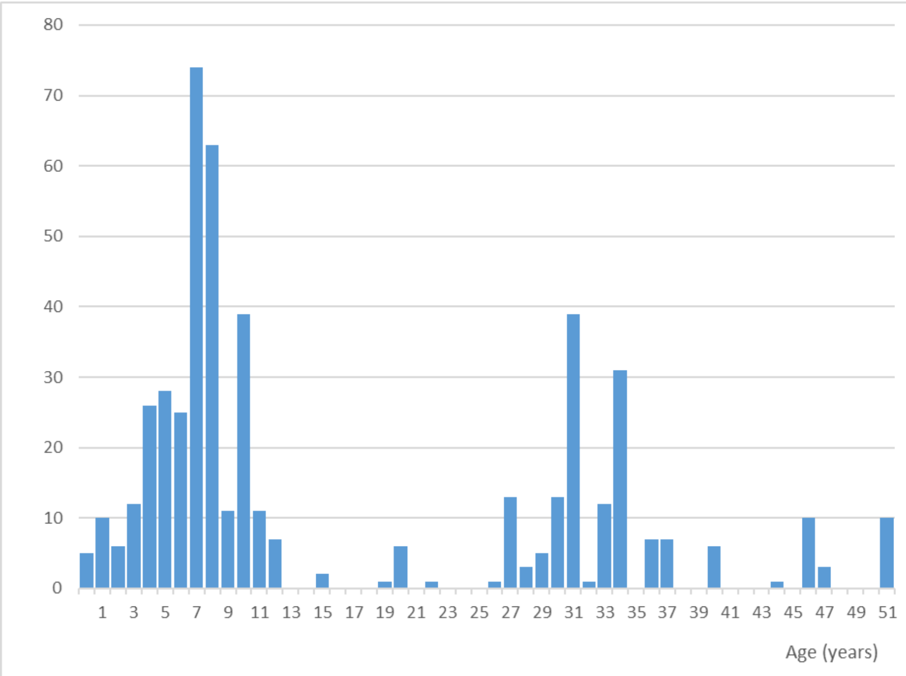

Figure 14-1: Age profile – all HV circuit breakers

The following charts illustrate the age profile according to certain asset parameters. Note that the following charts consider the age profile in 5-year bands, starting with 1965/66 to 1969/70.

Nominal operating voltage

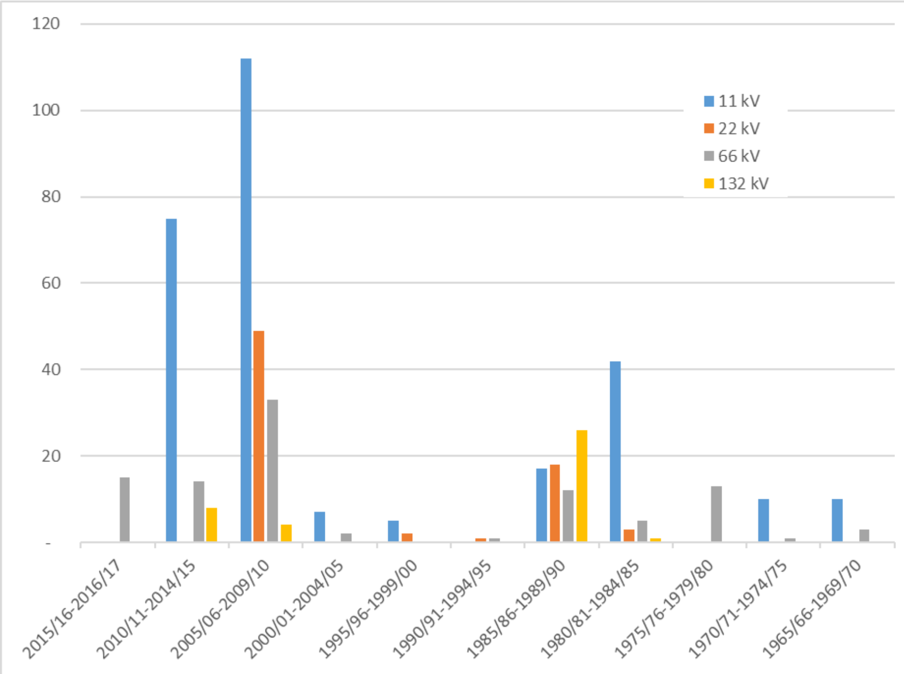

Figure 14-2: Age profiles according to operating voltage

Manufacturer

The following charts show the age profiles at each voltage level by manufacturer. They show quite clearly the high relative volumes supplied by Siemens since 2005, particularly at the 22 kV and 66 kV voltage levels.

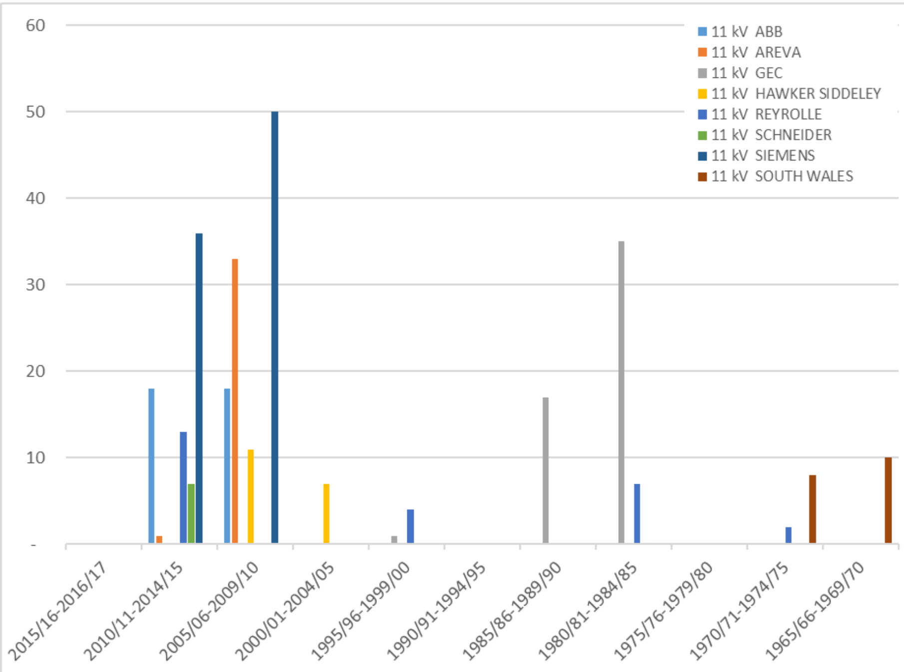

Figure 14-3: 11 kV circuit breaker age profile according to manufacturer

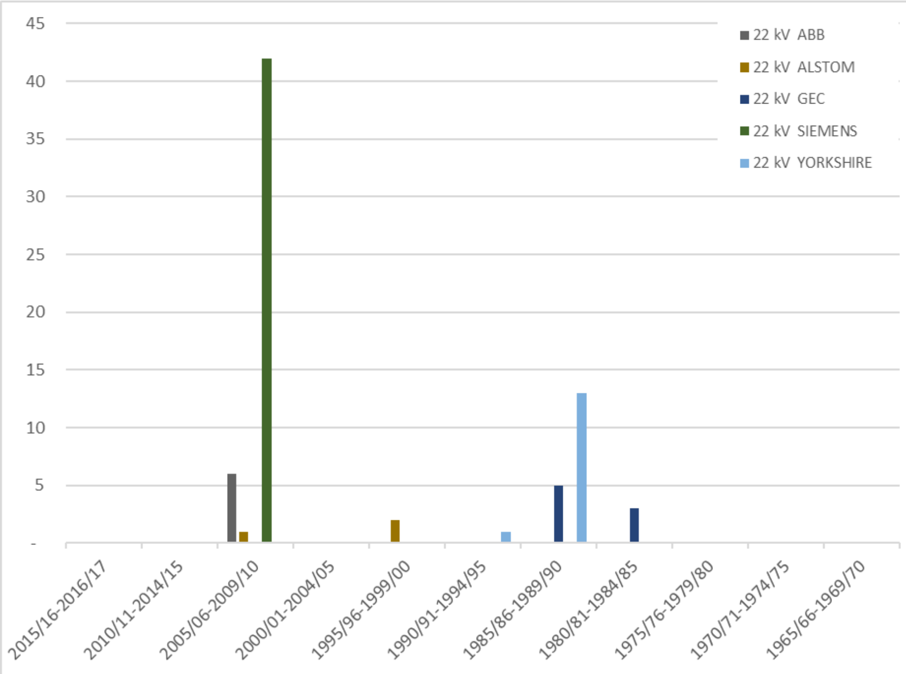

Figure 14-4: 22 kV circuit breaker age profile according to manufacturer

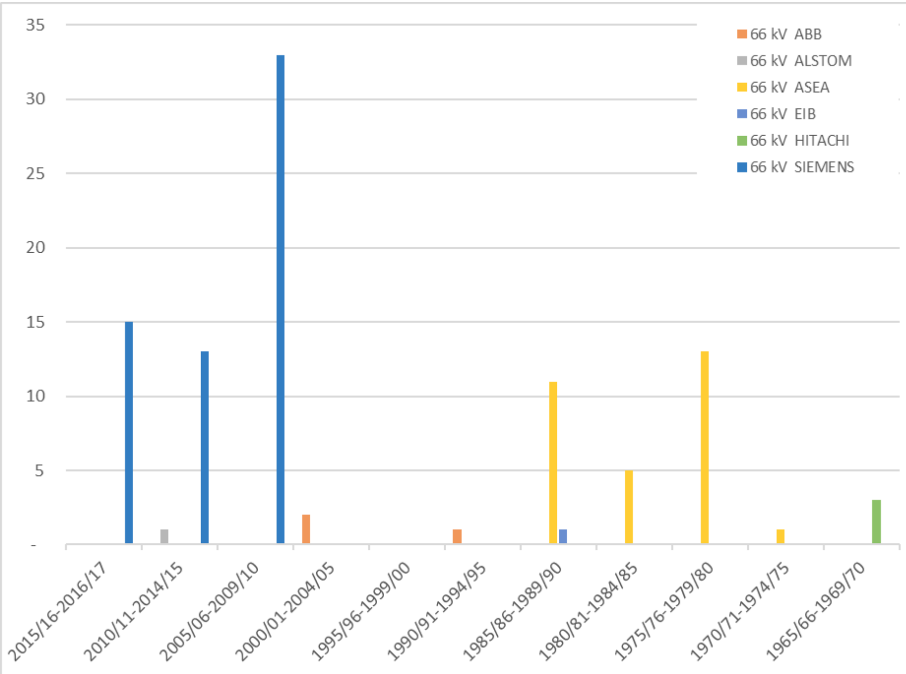

Figure 14-5: 66 kV circuit breaker age profile according to manufacturer

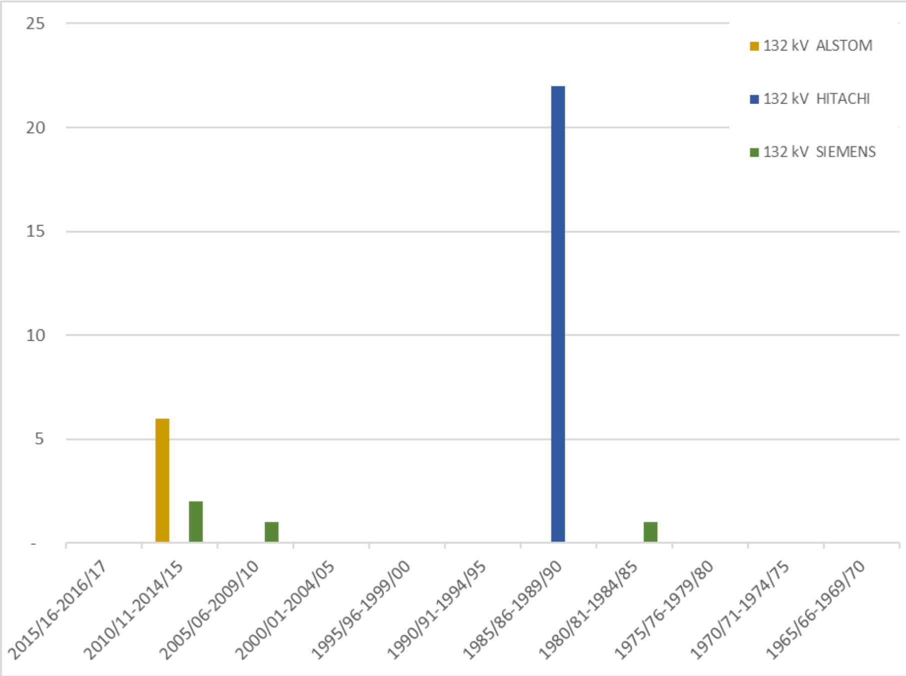

Figure 14-6: 132 kV circuit breaker age profile according to manufacturer

Interrupting medium

The following charts show the age profiles according to the interrupting medium used at each voltage level. At 132 kV, only SF_6 has been used by Power and Water. At other voltage levels the age profiles show the changes in design such that the current standards are: 11 kV and 22 kV – vacuum interrupters; 66 kV and 132 kV – SF_6 interrupters.

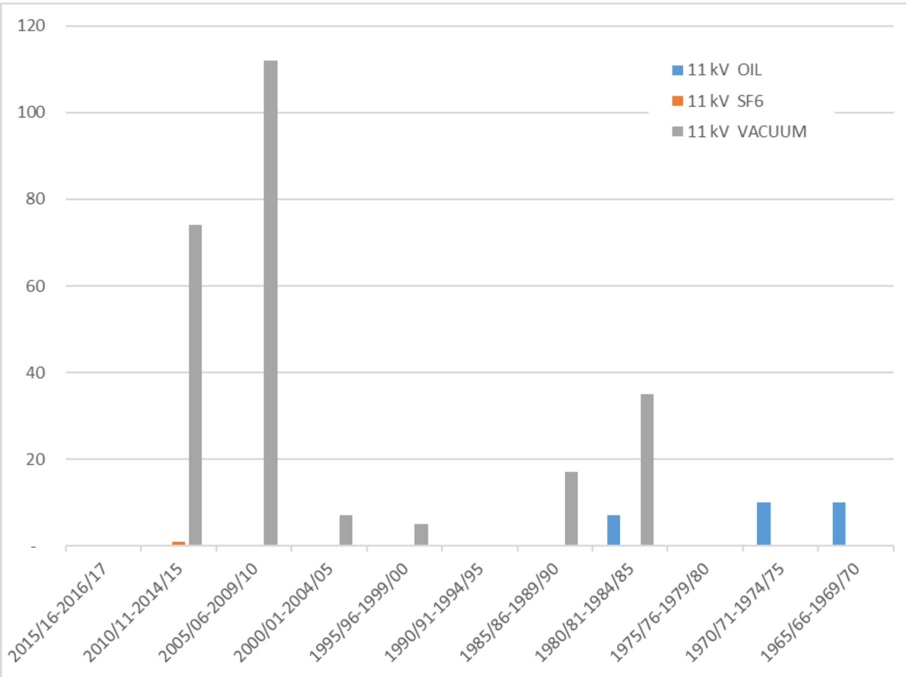

Figure 14-7: 11 kV circuit breaker age profile according to interrupting medium

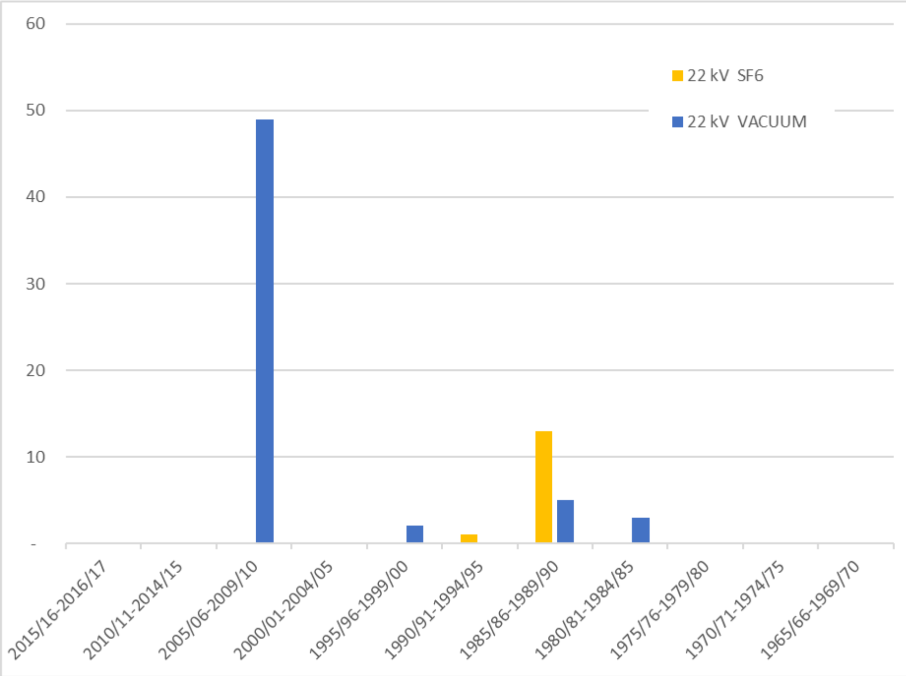

Figure 14-8: 22 kV circuit breaker age profile according to interrupting medium

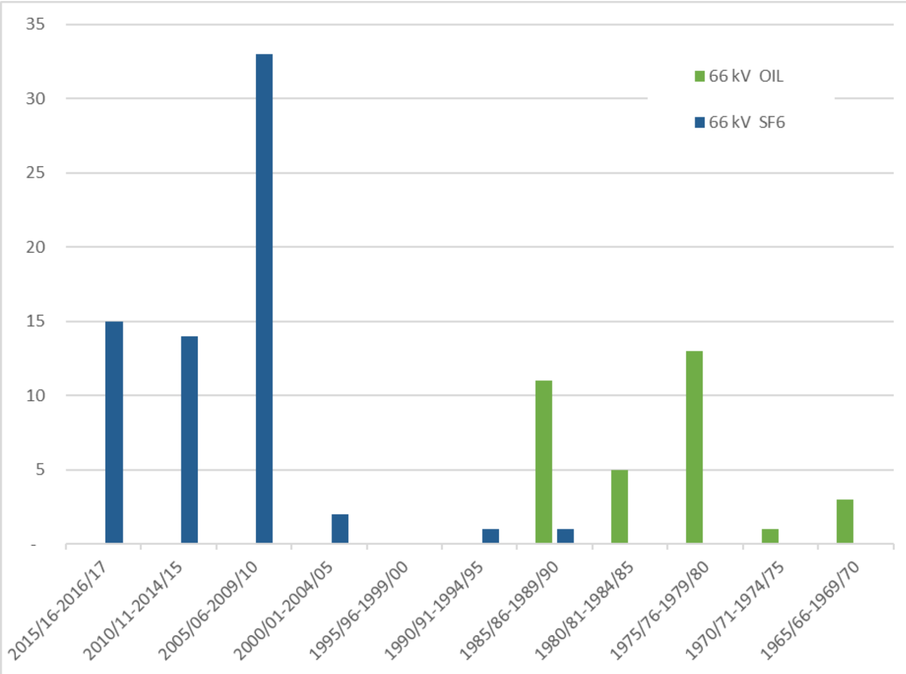

Figure 14-9: 66 kV circuit breaker age profile according to interrupting medium

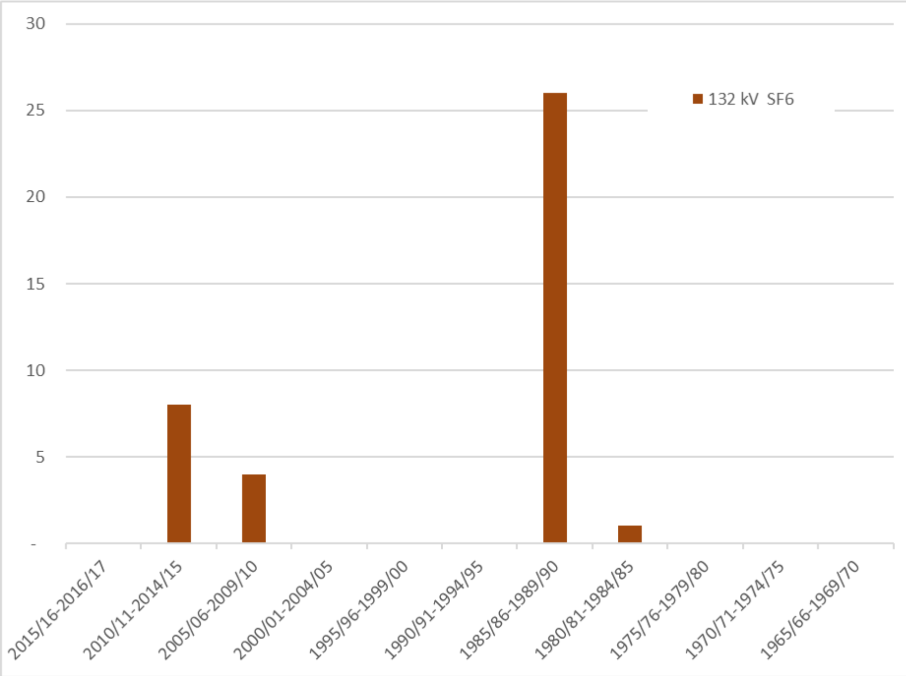

Figure 14-10: 132 kV circuit breaker age profile according to interrupting medium

Table 14.2: 11 kV circuit breakers by manufacturer, model and interrupting medium

Manufacturer	Model	Medium	Quantities			
			11 kV	22 kV	66 kV	132 kV
ABB	EDF SK1-1	SF6			2	
ABB	H/WSN	VAC		1		
ABB	H/WSN-24-06-25	SF6		6		
ABB	H/WSN-24-12-25	SF6		1		
ABB	HD4/W 24.12.25	SF6		3		
ABB	HD4/W-24-06-25	SF6		1		
ABB	PASS MO	SF6				3
ABB	VD4	VAC	36	6		
AEG	S1-145	SF6				4
ALSTOM		SF6			1	
ALSTOM	GL312 F1/4031 P/VE	SF6				6
ALSTOM	SBV24	VAC		3		
AREVA		SF6	1			
AREVA	HWX	VAC	33			
ASEA	HLC 72.5 /1600	OIL			22	
ASEA	HLC 72.5 /2000U	OIL			11	
ASEA	HLC 72.5/1250	OIL			2	

Manufacturer	Model	Medium	Quantities			
			11 kV	22 kV	66 kV	132 kV
EIB	HPFA 409k	SF6			1	
GEC		VAC	2			
GEC	AV24	VAC		5		
GEC	JB424	OIL		7		
GEC	OX36	VAC		3		
GEC	SBV	VAC	34			
GEC	SBV2	VAC	18			
HAWKER SIDDELEY	VMV 12/25/20	VAC	7			
HAWKER SIDDELEY	VMV 12/25/6	VAC	10			
HAWKER SIDDELEY	VMV/6/25	VAC	1			
HITACHI	CFPT-120-40	SF6				22
HITACHI	OSYGB-250	OIL			3	
REYROLLE		OIL	2			
REYROLLE		VAC	10			
REYROLLE	LMT2	OIL	7			
REYROLLE	LMVP/X7/QMRO	VAC	13			
REYROLLE	Type 2 LM 23VP	VAC	4			
SCHNEIDER	WSA	VAC	7			
SIEMENS	3AH5	VAC	10			
SIEMENS	3AH5124-2	VAC	10			
SIEMENS	3AH5125-2	VAC	20			
SIEMENS	3AH5135-6	VAC	8			
SIEMENS	3AH52	VAC	7			
SIEMENS	3AH5204-2	VAC	3			
SIEMENS	3AH5205-2	VAC	21			
SIEMENS	3AH5214-6	VAC	2			
SIEMENS	3AH5215-6	VAC	6			
SIEMENS	3AH5274-2	VAC		54		
SIEMENS	3AH5284-6	VAC		6		
SIEMENS	3AP1DT	SF6			33	
SIEMENS	3AP1F1	SF6				5
SIEMENS	8DN8	SF6			28	
SIEMENS	(blank)	VAC		8		
SOUTH WALES	C4X1	OIL	16			
SOUTH WALES	C8X1	OIL	2			

Manufacturer	Model	Medium	Quantities			
			11 kV	22 kV	66 kV	132 kV
YORKSHIRE	YSF6	SF6		14		
UNKNOWN	UNKNOWN	OIL		6		
UNKNOWN	UNKNOWN	SF6			1	
UNKNOWN	UNKNOWN	VAC	10	2		
		OIL	**27**	**13**	**38**	**0**
		SF6	**1**	**25**	**66**	**40**
		VAC	**272**	**88**	**0**	**0**
		Total	**300**	**126**	**104**	**40**