Asset Management Plan – Distribution Substations

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 its network of assets are distribution substation assets. Distribution substation assets 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 modest proportion to the total asset base *– however age compared to expected life is not a great concern.*

Distribution substations make up 12% of the total replacement value of the asset base and contribute to around 13% of the total operating expenditure. At an average age of 17.3 years the asset fleet is relatively young with 1.9%, or 91 assets projected to exceed the standard expected asset life of 45 years within the next regulatory period. This requirement for renewals can be managed through condition based assessment and a targeted replacement program is currently applied by Power and Water.

Assets operate across a diverse environment *– temperature, humidity, rainfall, soil type present different challenges 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, droughts, dust storms, 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.

There are 2 key challenges that require management *– corrosion and oil leaks.*

Key asset challenges include asset corrosion and oil leaks in the Darwin region where the assets are subject to high corrosion environments. Other asset challenges include winding related failures brought on by severe weather conditions, and cable termination failures associated with older paper lead cable installations. The greatest challenge, however, is the corrosion of the transformer body and/or gaskets which eventually leads to oil leaks and ultimately to transformer failures.

Power and Water operates a unique network of Single Phase Underground Distribution Substations (SPUDS). The SPUDS are mostly located in the front yards of residential properties and subject to watering and build-up of dirt, leaves, etc. The installation and environmental conditions maintain moisture beneath the tank and accelerates the corrosion of the base of the substation. As the corrosion is not visible, oil leaks develop over time, contaminating soil around the substation, and if undetected ultimately leads to internal flashover. Operationally, any maintenance and fault conditions on SPUDS result in excessive reliability impact as there is no ability to transfer load between substations. The location, failure mode, and operational issues presents an unacceptable safety and reliability risk associated with assets that are demonstrating an increasing rate of failure. Failure rates have increased to more than 30 outages associated with SPUDS in 2016/17 and a 2% contribution to system SAIDI.[1] Investment in the renewal of the SPUDS, involving refurbishment and replacement is proposed for the next regulatory period and is expected to continue in following regulatory periods.

Maturing condition data associated with distribution substation assets is a key asset management challenge. With increasing asset failures in a relatively young asset fleet an increased focus on the collection of corrosion and condition data and analysis are being put into effect to better support asset management decision making. Focused routine inspections and targeted methodical inspections prioritising high corrosion areas are some of the proposed undertakings aimed at improving data collection and analysis during business as usual activities.

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

The following distribution substation asset renewal programs are proposed for the next regulatory period, 2019/20 to 2023/24 to address key asset challenges:

- Single Phase Substation Replacement/Refurbishment program. A targeted replacement and refurbishment program to rectify corrosion defects and bring high risk SPUDS back to acceptable design standards.
- Distribution substation pooled replacement program. The pooled program captures those distribution substation assets that fail in service.

The renewal program has been developed with the objective of maintaining risk over time. To achieve this, an asset health and criticality framework was developed which is expected to provide a consistent method of assessing assets and making value based investment decisions. The health and criticality framework was central to establishing the targeted distribution substation asset investment programs focusing on the highest risk assets as a priority.

The investment programs are summarised as follows:

Table 1: Forecast renewal and maintenance expenditure for 2019/20 to 2023/24

Program	2019-20 ($ million)	2020-21 ($ million)	2021-22 ($ million)	2022-23 ($ million)	2023-24 ($ million)	Total ($ million)
Renewal Plans	$2.91	$3.16	$3.39	$3.56	$3.64	**$16.66**
Maintenance plans	$2.56	$2.56	$2.56	$2.56	$2.56	**$12.79**
Total	**$5.47**	**$5.72**	**$5.95**	**$6.12**	**$6.20**	**$29.45**

The forecast investment over the regulatory period has been compared to the AER's repex model output. As shown in Figure 1, Power and Water's forecast investment in distribution substations is correlated to the repex model's projection over the 2019-24 regulatory period and future regulatory period expenditure requirements are projected to be consistent with the 2019-24 period.

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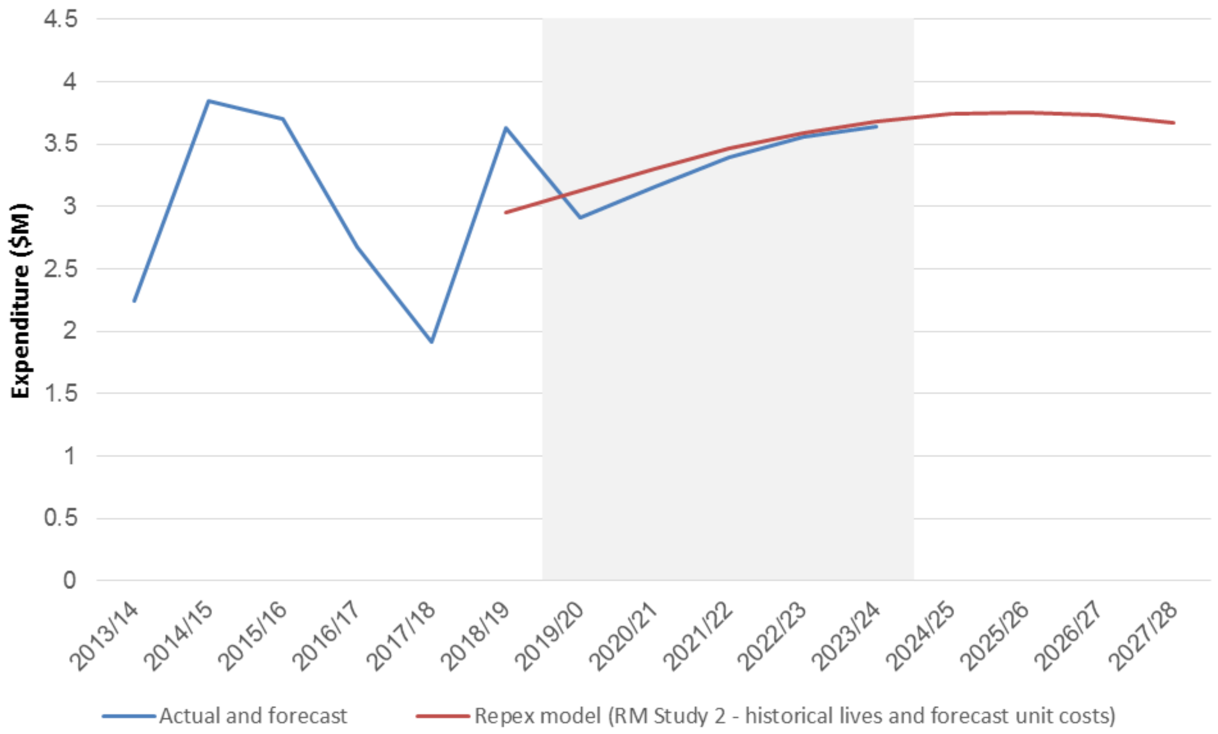
[1] BNI Document: NMP17 - Single Phase Substation Replacement/Refurbishment

Whilst there is good correlation in expenditure forecasts, the underlying age-based approach used in the repex model is not the driver for Power and Water's investment forecast which is targeted and based on asset condition.

Figure 1: Investment in distribution substations over the regulatory period



<u>Benefits from the investment program</u> *– reliability improvement*

The proposed investment in distribution substation renewal is expected to reduce the contribution from distribution substations to system SAIDI by around 0.7%, and the SAIFI contribution with up to 0.8% over the next regulatory period.

With investment and including for growth over the next 5 year regulatory period the health and criticality profile for distribution substations is expected to change to that shown in the second table below. The mitigated risk is demonstrated in the number of assets that transfer from the H3 health category. For the distribution substation assets, a reduced risk is reflected in a 100% reduction in the number of poor health assets in the H3, and 37% reduction in the number of medium health assets in H2.

Distribution substations health-criticality matrix (qty) by 2023/24, with no investment

	H1	H2	H3
C1	3,124	142	359
C2	845	146	112
C3	167	48	71

Distribution substations health-criticality matrix (qty) by 2023/24, with investment

	H1	H2	H3
C1	3,418	207	
C2	1,100	3	
C3	284	3	

The movement in risk demonstrated by the movement of assets predominantly from the poor health and applicable criticality zones substantiates Power and Water's investment strategy that targets the highest risk assets.

The risk profile snapshot has been based on the current understanding of the distribution substation asset class age, condition, and operating environment. The risk profile is expected to evolve as ongoing condition and performance monitoring, methodical inspections, and improved data collection practices provide for better quality data and asset insights.

1 Purpose

The purpose of this asset management plan (AMP) is to define Power and Water Corporation's (Power and Water) approach to managing the life-cycle activities for distribution substation assets. It defines the rationale and direction that underpins the management of these assets into the future:

- Short Term (0-2 years): Detailed maintenance and capital work plans for the upcoming financial year based on current asset condition.
- Medium Term (2-5 years) 2019-24 Regulatory Period: Strategies and plans based on trends in performance and health indicators.
- Long Term (5-10 years) 2024-29 Regulatory Period: Qualitative articulation of the expected long-term outcomes.

The distribution substation 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 2.

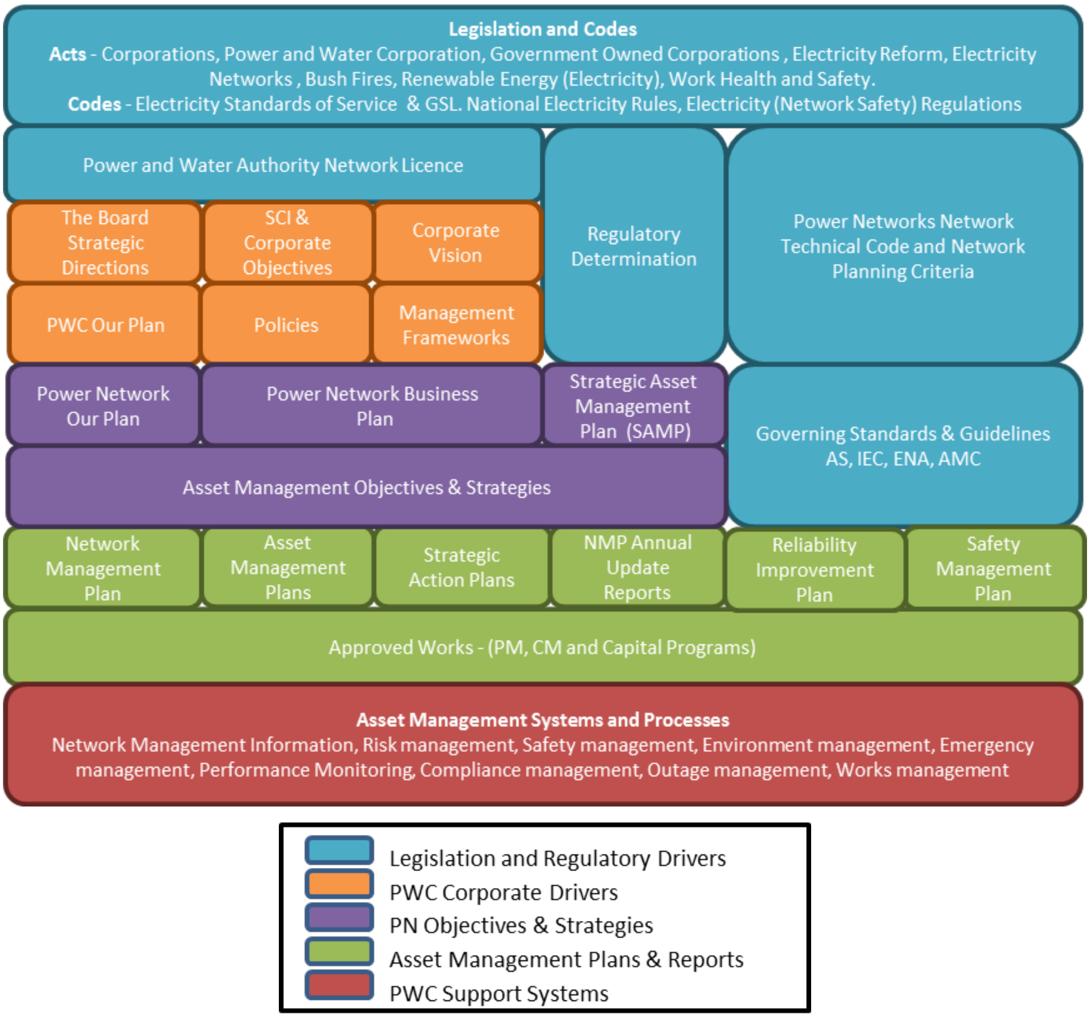


Figure 2: Asset management system

2 Scope and objectives

2.1 Asset class overview

In-scope assets include Power and Water’s distribution substations which include three main sub classes namely ground, pole mounted and packaged, see Table 2 for overview.

Table 2: Overview of in-scope assets

Sub Class	Quantity	Voltage	Average Age (years)	Nominal Lifespan	% exceeding lifespan in forecast period	Key Points
Ground	293	11	21	45	5.1%	• Corrosion and oil leaks at gaskets impacts reliability • Animal interference add to reliability reduction
	52	22	20.4	45	17.8%	
Package	1,174	11	16.9	45	0.2%	• Corrosion and oil leaks at gaskets impacts reliability • SPUDS require replacement and refurbishment • Partial discharge issues at some installations require capital to resolve • Animal interference
	123	22	17.4	45	0.0%	
	322	6.35	33.7	45	0.0%	
Pole	722	11	16.4	45	3.5%	• Corrosion and oil leaks at gaskets impacts reliability • Animal interference • Lightning strikes
	2,123	22	14.7	45	1.9%	
Total	**4,809**		**17.3**	**45**	**1.9%**	

The distribution substation asset class make up a significance proportion of Power and Water’s assets and activities. This is because much of the network is supplied using overhead assets. Currently, the distribution substation asset class comprise:

- 12% of the network by replacement value;
- 13% of operational expenditure (opex);
- 5% of capital expenditure (capex), including:
    - 8% of replacement expenditure (repex); and
    - 1% of augmentation expenditure (augex).

Power and Water’s distribution substation assets are distributed throughout its network footprint which covers the Northern Territory (NT).

2.2 Asset class function

Distribution substations convert distribution voltages to 230/415V for consumers to use. They are located close to groups of consumers to accommodate the low voltages that cannot be distributed more than less than 0.5km without the impact of voltage reduction. The function of distribution substations within Power and Water's electricity network is illustrated by Figure 3.

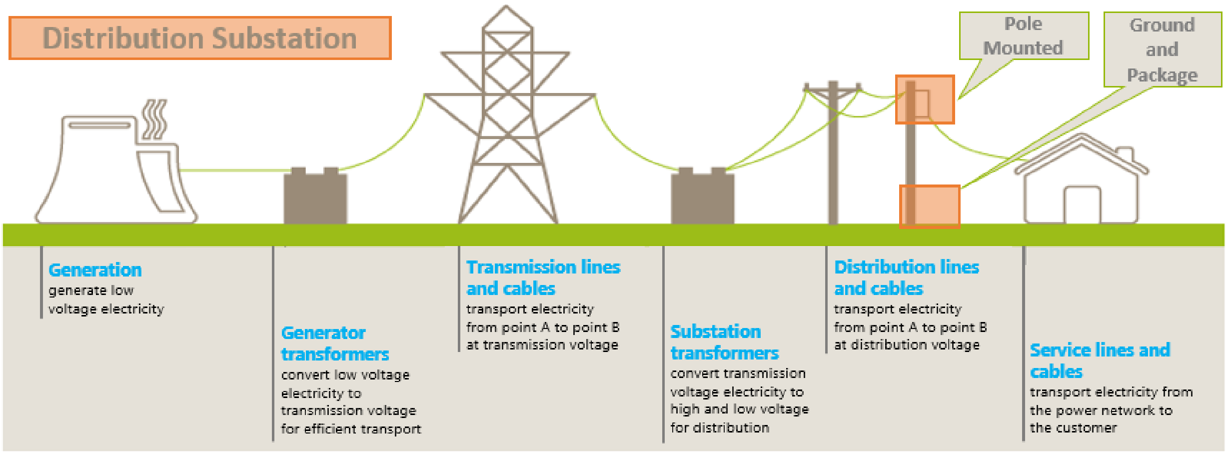


Figure 3: Diagram of in-scope assets

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 4.

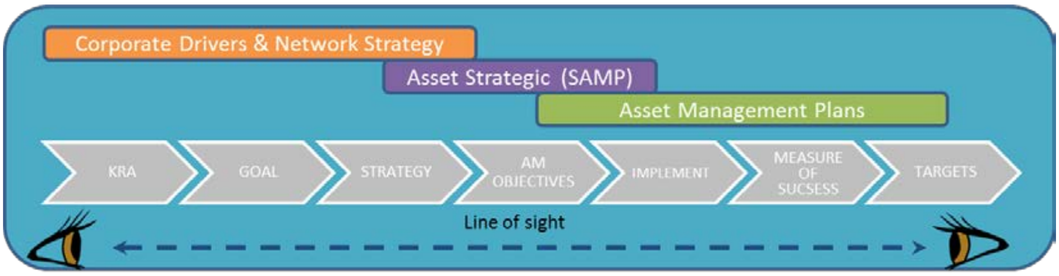


Figure 4 Asset Management Line of sight from Corporate and Network strategies through the Asset Management objective to the targets in the asset management plan.

Table 3 provides 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 3 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	• Vehicle Impacts of unprotected assets • Electric shocks or near misses due to exposed conductors • Unauthorised access • Total asset class specific safety incidents	• Total asset class specific safety incidents not exceeding 25 per annum

Objectives	Measures	Targets
• Engage with our customers, community and stakeholders to demonstrate that we have delivered the best possible solutions	• Customer Feedback - Track complaints	• Number of Complaints 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 • Fires starts caused by asset failure	• 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.	• Asset class contribution to system SAIDI • Asset class contribution to system SAIFI • GSL contribution per year Guaranteed Service Levels	• SAIDI to be no more than 8% for this asset class. • SAIFI to be no more than 8% for this asset class. • GSL contribution per year TBA
• Proactively and systematically measure the network power quality	• Asset class related number of poor power quality incidents.	• TBA
• Ensure that the systems and processes provide sufficient and appropriate financial data • Understand the financial risks associated with asset management	• Whole of life cost of assets • 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 analaysis 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) • Compliance breaches with the relevant legislation / regulation / standards. • Asset class preventative maintenance completion	• Achieved

3 Context

3.1 Roles and responsibilities

Power and Water operates using an “Asset Owner / Asset Manager / Service Provider” business model. Although there is extensive collaboration and interfacing between the roles, generally speaking:

- 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.

3.1 RACI

The Responsibility, Accountability, Consulted, Informed (RACI) matrix for the distribution substation asset class is provided in Table 4. This defines the roles and accountabilities for each task by allocating to specific roles/personnel in Power and Water.

Table 4 RACI matrix for Distribution substations

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	Field Services Manager	Works Management Manager	Strategic Asset Engineering	Asset Quality & Systems
Establish Condition Limits		A	C	C		I	I	C/I	I	R	I
Performance and condition data analysis	I	A	I	I		I	I	I	I	R	I
Plan capital works (Options, costs, BNIs, BCs etc)	I	R	A		C/I	R	R	R	R	R	I
Execute maintenance plans	I	I	I			A	A	R	R	C/I	I
Deliver identified major projects and programs of work	I	C	A	C	R	R	R	C/I	C/I		
Manage asset data (data entry, verify data)		A	I	I						C/I	R
Monitor delivery of capital plans and maintenance	I	A	I	I	I	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.*

4 Asset base

4.1 Overview

Power and Water owns and maintains a portfolio of 4,809 distribution substations across the four regions of Alice Springs, Darwin, Katherine, and Tennant Creek, with the largest population in the Darwin Region.

The distribution substations function across the different network voltage levels including LV (415V) and HV (6.35kV, 11kV, 22kV). The asset class for distribution substations can be broken down into three types namely ground (mainly substations within a building and a few outdoor fenced substations), package (enclosed unit, kiosk/mini-substation) and pole mounted.

4.2 Asset types

An overview of the different distribution substation installations per voltage and region is provided in Table 5.

Table 5: Distribution substations per region and voltage

Region	Period of installation	Voltage levels	Capacity	Challenges	Expenditure / risk implications
Alice Springs	*1961 – present*	• 11kV • 22kV	• 150MVA • 42MVA	• Early surface corrosion	
Darwin	*1961 – present*	• 6.35kV • 11kV • 22kV	• 17MVA • 765MVA • 157MVA	• Progressive structure corrosion	• Diminishing remaining life of distribution substations as result of progressive corrosion deterioration • Increased risk of electrical shock to public and workers • Negative impact on system reliability performance • Increasing refurbishment expenditure requirements
Katherine	*1962 – present*	• 11kV • 22kV	• 6MVA • 89MVA	• Early surface corrosion	
Tenant Creek	*1962 – present*	• 11kV • 22kV	• 0.7MVA • 27MVA	• Early surface corrosion	

4.3 Asset population analysis

A detailed breakdown of the distribution substations is provided in Figure 5 and Figure 6 which presents the different asset types with capacities per region and voltage. Only the Darwin region have assets at 6.35kV which refers to Single Phase Underground Distribution Substations (SPUDS) of which there are 318 in service.

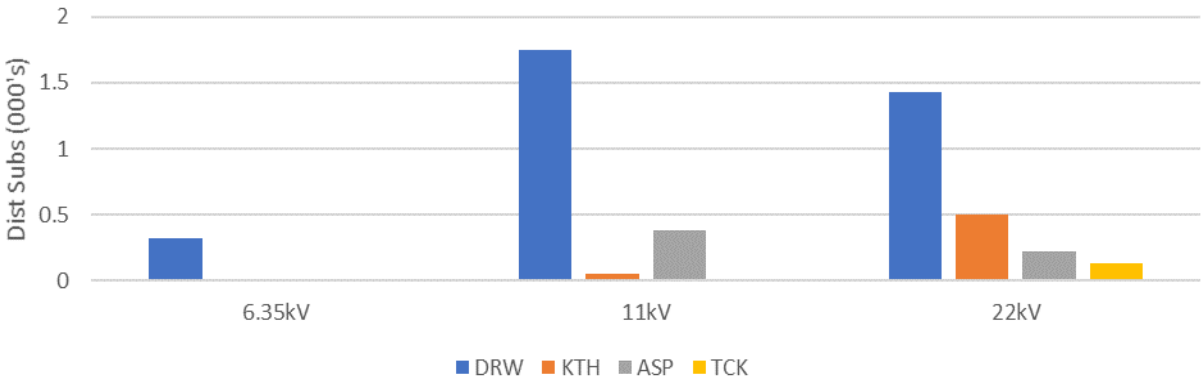


Figure 5: Distribution substations per voltage and region

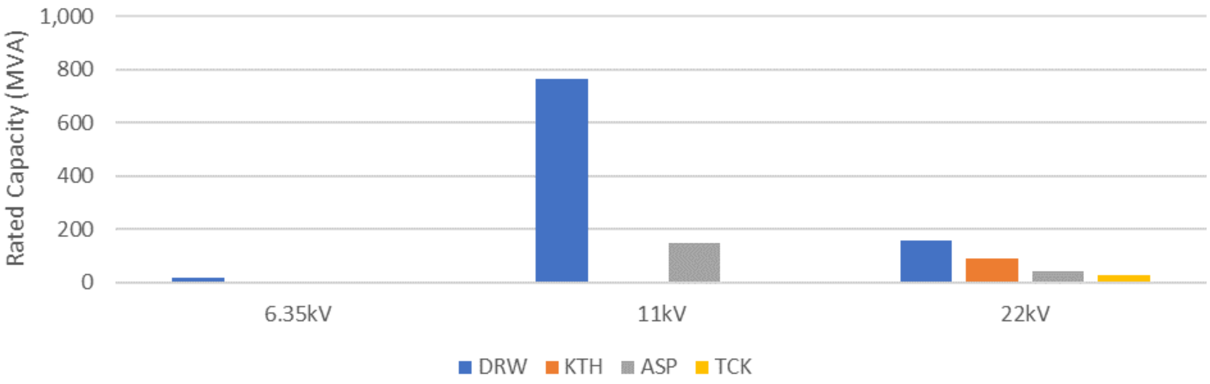


Figure 6: Distribution substations capacity per voltage and region

Figure 7 present the distribution substation per sub category and voltage. It is evident that pole mounted and package substations make up the bulk of the population.

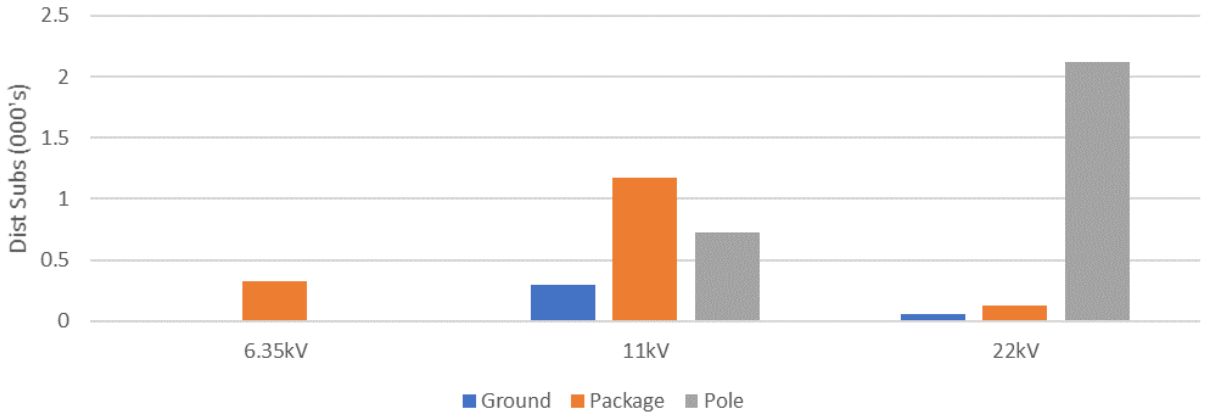


Figure 7: Distribution substations per sub category and voltage

Figure 8 shows the distribution transformer capacities used within the Power and Water network. The most common sizes are 500kVA, 300kVA and 100kVA. The large range of transformer capacities is indicative of legacy approach that was not as standardised. This design phase challenge is being addressed as described in the lifecycle asset management approach provided in Appendix A.

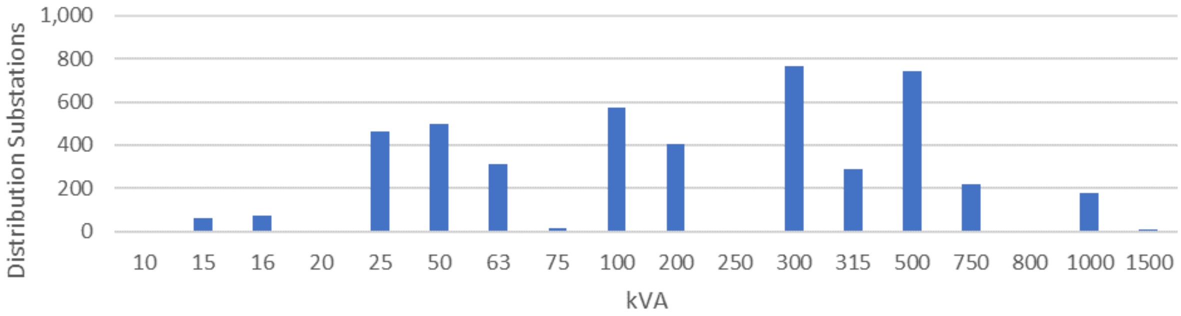


Figure 8: Distribution substation quantities per capacity

Figure 9 provides insight into the manufacturers used per region and indicates that the asset base consists mostly of Tyree, Wilson and ABB distribution transformer types.

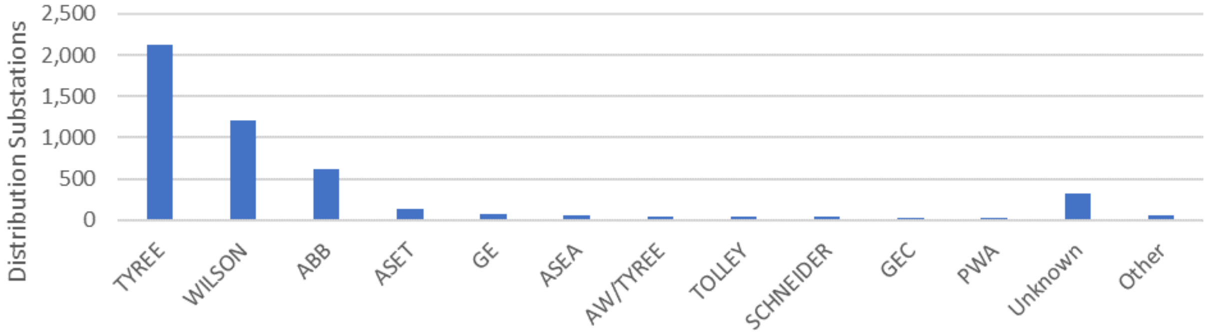


Figure 9: Distribution substation manufacturers

4.4 Asset profiles

4.4.1 Distribution substations - Ground

The ground mounted substation population shows evidence of consistent growth over the last 20 years. The strongest growth has been in the Darwin region, although growth was evident throughout the system with relative installation increases evident in Katherine, Tennant Creek and Alice Springs.

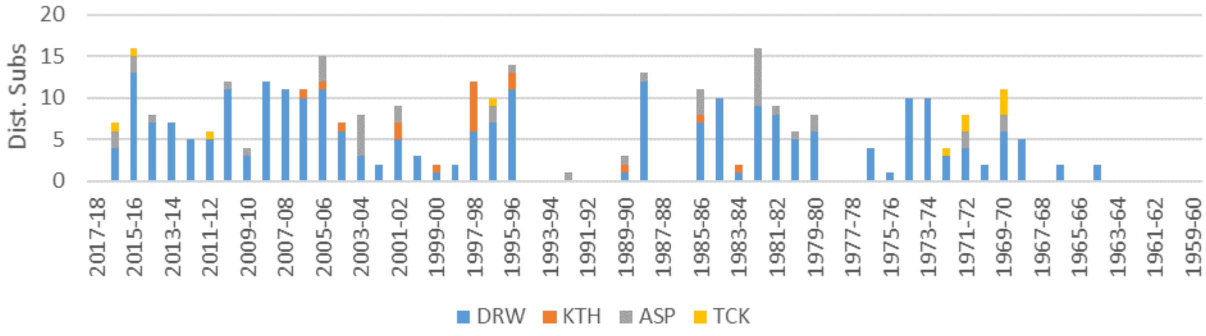


Figure 10: Distribution substation ground install age profile per region

4.4.2 Distribution substations - Package

Figure 11 shows a large peak in package/kiosk type installations in the early 1980's with consistent growth also present during the 2000's. Growth has been predominantly in the Darwin and Alice Springs regions.

The strong growth in the Darwin region coincides with large gas resource development projects that launched during this period in the northern part of the Territory. Most of these major resource projects are now coming to a close transitioning from construction to operations and is expected to coincide with a corresponding reduction in employees. This can be linked to the reduced requirement for residential type package/kiosk substation installation in the most recent years.

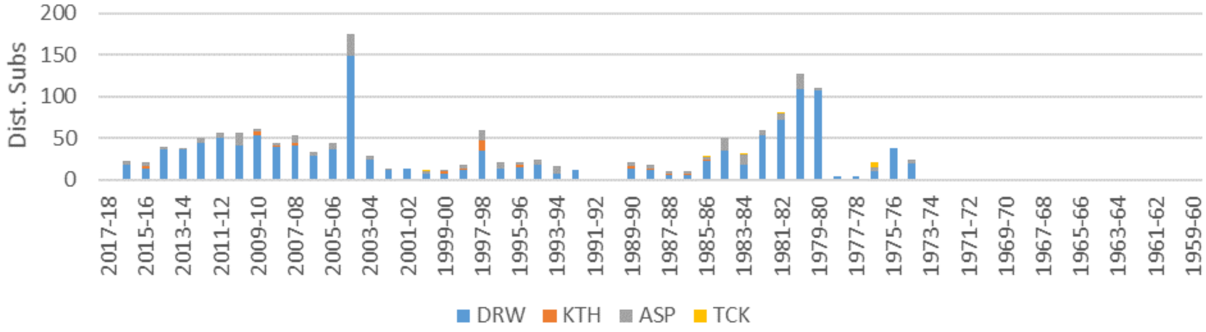


Figure 11: Distribution substation package install age profile per region

4.4.3 Distribution substations – Pole mounted

Figure 12 indicates an increased installation of pole mounted distribution transformers in the past 15 years. Similar to package substations, the pole substation population has grown substantially over the last 15 years, as shown in Figure 12. The growth coincides with large gas resource development projects that launched during this period in the northern part of the Territory. Most of these major resource projects are now transitioning from construction to operations with a corresponding reduction in staff. This can be linked to the reduced requirement for pole mounted substation installations in the most recent years.

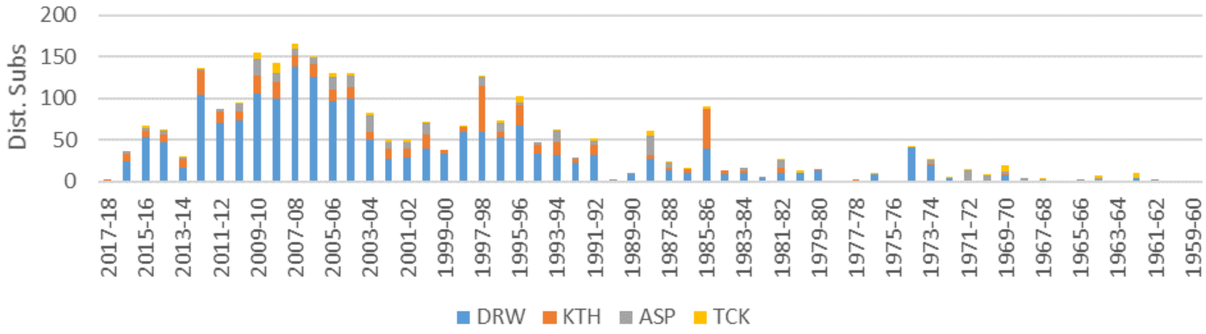


Figure 12: Distribution substation pole mounted age profile per region

4.4.4 Standard Asset Life

The asset life is the period of time that an asset can be expected to reliably and efficiently provide the service capability for which it was designed. Understanding the asset life is important to the establishment of a suitable maintenance regime including a planning and recording system together with its impact on capital and operational expenditure forecasts.

The situation and environment in which an individual asset operates can have a significant impact on both the required level of reliability and the rate of asset deterioration. The asset life is typically determent by factors such as:

- the cost of maintenance versus the cost of replacing the asset;
- the maintainability of the asset, particularly if replacement components are no longer available;
- the risk associated with the failure of the asset, particularly if the consequence of failure increase to unacceptable level.

It is therefore important to note that the asset life represents an average expected life of the asset. Some individual assets will last much longer than the expected asset life and others will fail prematurely.

The asset lives applied by Power and Water as a standard have been based on in-house engineering experience and judgement, supplemented by general industry experience across the NEM. The asset life is also referred to in the AMP as the replacement life or the economic life referring to the expected life at which the asset is typically replaced or renewed.

A standard replacement life of 45 years was applied to the distribution substation assets. It corresponds with the economic replacement asset life applied by Power and Water in asset valuations and compares with the lower range of lives observed across the National Electricity Market (NEM) as demonstrated in Figure 13. The low asset life is reflective of a high replacement rate as result of corrosion, oil leaks, and lightning strikes commensurate with the climate and weather conditions within which the power network operates.

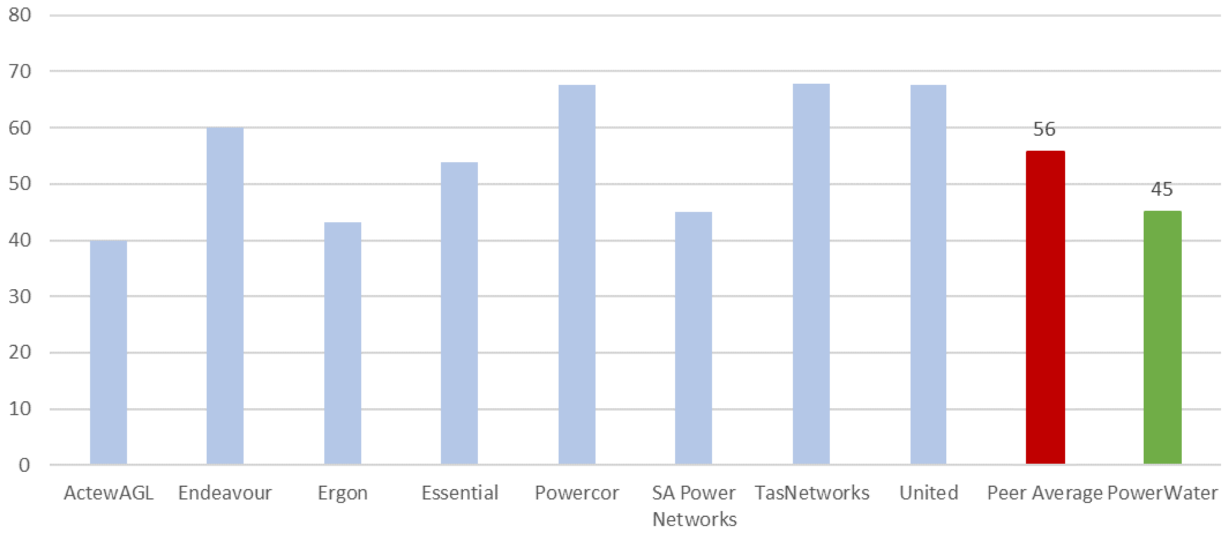


Figure 13: Distribution substation replacement life

4.4.5 Age profiles

The distribution substation asset age profile indicates an asset fleet approaching mid-life with the average age for pole mounted assets being the lowest. Notwithstanding the relative low average age of the assets, the number of assets exceeding the standard asset life increases rapidly over the next two regulatory periods.

Assets in the Tennant Creek and Alice Springs regions are older than other regions and already over 16% and 7% of these assets respectively exceed the standard asset life. The regions, however, only represents 14.7% of the population and does not have a large effect on replacement volumes.

Table 6: Distribution substation average age and remaining life

Region	Sub class	Average Age (years)	Average Age (years)	Weighted Average Remaining Life (years)	% of asset population	% exceeding replacement life in 2017	% approaching replacement life by 2024	% approaching replacement life by 2029
Alice Springs	Ground	23,0	19.1	25.9	12.7%	4.1%	9.6%	19.8%
	Package	20,8						
	Pole	20,2						
Darwin	Ground	21,8	17.1	27.9	72.7%	1.2%	6.6%	18.7%
	Package	20,5						
	Pole	14,8						
Katherine	Ground	19,4	15.0	30.0	11.6%	0.4%	1.2%	2.7%
	Package	16,2						
	Pole	16,2						
Tennant Creek	Ground	30,1	22.0	23.0	3.0%	15.8%	27.1%	31.6%
	Package	35,1						
	Pole	22,3						
All regions	Ground	22,1	17.3	27.7	100.0%	1.9%	6.9%	17.4%
	Package	20,5						
	Pole	15,9						
Note: *some asset information not confirmed and linked to a region								

4.4.6 Distribution Substation – Age profiles by region

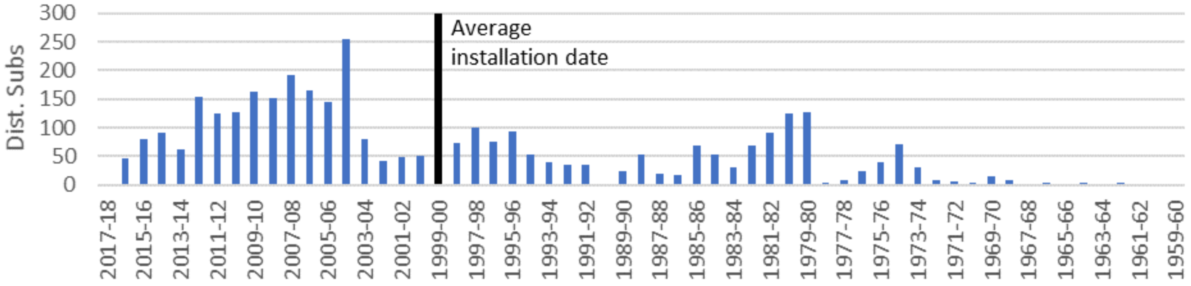


Figure 14: Darwin – Distribution substation age profile

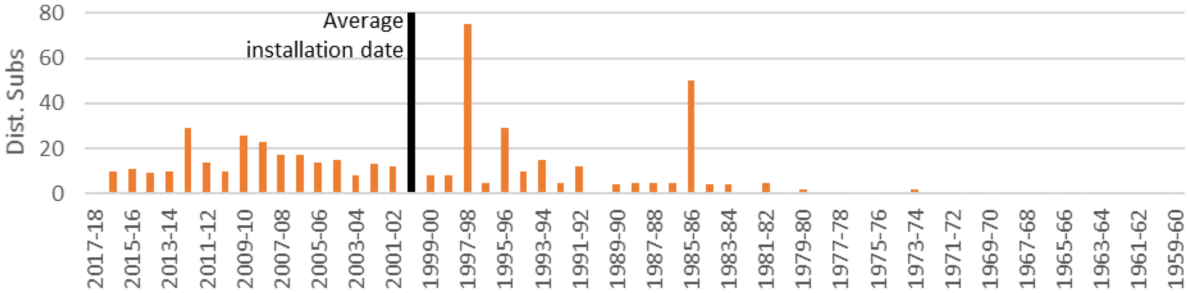


Figure 15: Katherine - Distribution substation age profile

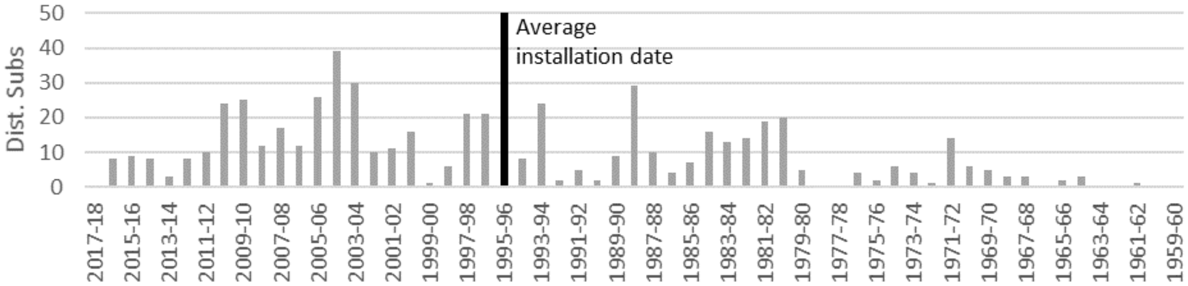


Figure 16: Alice Springs - Distribution substation age profile

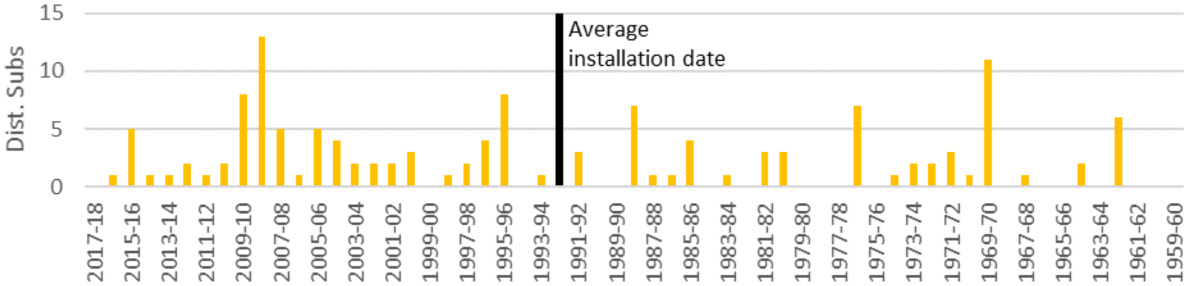


Figure 17: Tennant Creek - Distribution substation age profile

5 Health and criticality profiles

5.1 Health and criticality indices

Risk is that uncertain event or condition associated with an asset failure that, if it occurs, will affect Power and Water's ability to successful execute its strategies to achieve its organisational objectives of operating a safe and reliable power network at the lowest cost to the customer. The health and criticality framework[2] provide the basis for calculating the risk associated with the distribution substation assets. It combines failure data and recent condition data (routine visual inspection, targeted methodical inspection, and testing results) to modify the assessment of expected remaining life and the associated likelihood of failure across the fleet of distribution substations.

The health and criticality indices developed for distribution substations establishes the context of the risk associated with these assets and defines the parameters that influences how the risk is

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[2] 'Asset Heath and Criticality Method' decision making process discussion paper

managed. Asset health is a key driver in the likelihood of asset failure, and the asset criticality is a key determinant in quantifying the risk associated with the failure.

It should be noted that the health and criticality indices rely heavily on available asset data and evolves as the quality of data regarding asset age, condition and operating environment improves. It will continue to evolve over time as the asset composition changes with age, investments, and network development. These changes are captured during routine inspections and targeted methodical inspections aimed at recording and updating asset data related to age, condition, and operating environment. These processes and practices are continuously being improved within Power and Water.

The probability of asset failures and the associated risks are therefore continually refined as routine data, and targeted data is collected across the asset base.

Distribution substations have a key reliability of supply function within the electrical network. The risk associated with the functional failure of distribution substations is extended outages impacting large quantities of customers.

5.1.1Asset health

The underlying failure mode for distribution substations is structural degradation resulting from corrosion and oil leaks leading to a deterioration in the asset health, and ultimately the functional failure of the asset. The deterioration in asset health is accelerated by factors such as design defects, third-party impacts, and damage during severe weather events. The main failure modes observed on the distribution substation assets are summarised in Table 7.

Table 7: Distribution substation failure modes

Failure mode	Description
Structural degradation	Structural degradation as result of corrosion ultimately leading to electrical failure as result of a loss of insulating oil and functional failure
Structural damage	Structural degradation as result of vehicles colliding with overhead and ground mounted distribution substation installations, debris strikes, and wind force during severe storm events ultimately leading to functional failures
Electrical damage	Electrical damage as result of lightning and switching surges ultimately leading to functional failure.

Power and Water assesses and records asset condition during routine inspections, as part of other works in the vicinity, through targeted methodical inspections and testing, and through an assessment and analysis of asset disposal options.

- Methodical inspections done by Power and Water on distribution substations in the Darwin region found ground mounted assets in need of refurbishment as result of corrosion issues. These assets were generally older than 35 years.
- The *AS/NZS 2312 - Guide to the Protection of Structural Steel Against Atmospheric Corrosion by the Use of Protective Coatings*, and a study on corrosion rates developed by Wattyl Industrial Coatings in 2004 (*GUIDE TO AS/NZS 2312:2002*) provides some guidance on the disparate corrosion related issues observed by Power and Water in the power network. The coastal area of Darwin is identified as an area subject to higher corrosion rates, whereas the inland areas of the power network are subject to relatively lower expected corrosion rates.

- Asset disposal assessments done to consider the disposal or repair opportunities on distribution substations removed from operation determined that the vast majority suffered degradation as result of extensive corrosion and oil leaks. Although some assets developed oil leaks earlier the majority of the distribution substations with extensive corrosion and oil leaks were aged 19 years and older.

The outcomes of the inspections and studies mentioned above have been used to inform the distribution asset health segregation. Where insufficient condition data was available, asset age or remaining life was used as a proxy for asset health.

Recent fault rates and test results were used to assess the probability of asset failure across the individual asset health categories.

5.1.2 Asset criticality

The distribution substation assets contribute to both the reliability and safety risk of the power network. Risk quantification undertaken in the industry across asset classes has found reliability risk to routinely be the more prominent risk associated with asset failures. Reliability risk is that risk related to the duration and frequency of outages resulting from asset failures linked to the number of customers impacted by an outage.

The criticality of the distribution substation assets within the network has in the first instance been based on the expected contribution to system reliability risk resulting from asset failure.

5.1.3 Distribution substations

The main failure mode identified for distribution substations is corrosion of the transformer body. This is a time-based degradation influenced by climatic environments. The climatic environment changes for ground mounted, package, and pole mounted substations affect the lifetimes of the assets. Ground mounted substations are typically located indoors with lower expected corrosion rates, package substations are installed outdoors on plinths maintaining moisture beneath the tank and accelerating the corrosion of the base of the substation. Pole mounted substations are typically exposed to severe weather events, but are not expected to have the same level of corrosion as package substations.

Health segregation of the assets has therefore been done based on corrosion zones, installation type, and age. The criteria applied to allocate a health score are provided in Table 8. Assets with unknown remaining lives were assigned a good health score, H1.

Table 8: Health indices criteria

Health score	Description	Criteria
H1	Good	All distribution substations outside of Darwin region Pole and Ground mounted substations in Darwin region and more than 15 years remaining life Package substations in Darwin region and more than 10 years remaining life
H2	Average	Pole and Ground mounted substations in Darwin region and between 5 and 15 years remaining life Package substations in Darwin region and between 5 and 10 years remaining life
H3	Poor	All distribution substations in Darwin region and less than 5 years remaining life

Where known poor asset health conditions have been identified through targeted inspections and testing, these assets' health have been adjusted to reflect the expected condition based remaining life. SPUDS are mostly located in the front yards of residential properties subject to constant watering and accelerated corrosion of the base of the substation. Corrosion of the transformer tanks has been identified as the primary failure mode resulting in oil loss and leading to oil contamination and functional failure. Functional failures resulting in potential inadvertent contact, electrical shock and catastrophic breakdown have been identified as key risks. With most of the SPUDS reaching the end of their functional life earlier than expected, the expected asset life for SPUDS have been adjusted to 35 years, i.e. the average age of the SPUDS population. This life is 10 years shorter than the 45 years expected asset life for distribution substations.

The health criteria described in Table 8 was also applied to the SPUDS using the shorter asset life.

Criticality allocations were in the first instance made based on the number of customers likely to be impacted from asset failures. The substation rating was used as a proxy for the expected number of customers connected to the substation, and likely to be impacted from the substation failing. The criteria that was applied is summarised in Table 9.

Table 9: Distribution substation criticality criteria

Criticality score	Description	Criteria
C1	Low	Substation rating <= 100kVA
C2	Medium	Substation rating > 100kVA and <= 500kVA
C3	High	Substation rating > 500kVA

Operationally, any maintenance and fault conditions on SPUDS result in excessive reliability impacts since there is no ability to transfer loads between substations. This reliability issue, combined with safety risks to the public and workers resulting from unpredictable issues related to the tank corrosion of the SPUDS, has led to the criticality of SPUDS being adjusted. The criticality adjustment has been made based on the number of fault events experienced on each SPUDS over the last 4 years. Table 10 provides a summary of the criticality criteria applied to SPUDS.

Table 10: SPUDs criticality criteria

Criticality score	Description	Criteria
C1	Low	No planned and unplanned fault events - July 2013 to Jun 2017
C2	Medium	More than 1 planned and unplanned fault events, but less than 2 - July 2013 to Jun 2017
C3	High	More than 2 planned and unplanned fault events - July 2013 to Jun 2017

The distribution substation health and criticality profile is provided in Table 11. It prioritises around 158 substations in the red and orange zone as being of poor health and higher criticality.

Table 11: Distribution substation health-criticality matrix (qty)

	H1	H2	H3
C1	3,038	112	323
C2	901	105	52
C3	172	50	56

With no investment and excluding growth over the next 5year regulatory period the profile is expected to change to that shown in Table 12. The increase in risk is demonstrated in the increase in the number of assets that entered the H3 health category.

Table 12: Distribution substation health-criticality matrix (qty) with no investment

	H1	H2	H3
C1	2,972	142	359
C2	800	146	112
C3	159	48	71

6 Key challenges

6.1 Environmental challenges

The network covers a range of environments and geographies which present different challenges for the distribution substation asset class. Table 13 provides an overview of environmental challenges in relation to managing Power and Water's distribution substation assets across its four operating regions.

Approximately 80% of Power and Waters network is coastal tropical environments prone to cyclones, monsoons, high ambient temperatures and humidity, and high annual rainfall. The remainder of the network is desert environments subject to high ambient temperatures, occasional flooding, droughts, dust storms, and aggressive soil conditions.

The unique environment results in a more rapid rate of asset deterioration, and lower worker productivity compared to peer distribution businesses.

Climate change is also expected to further exacerbate the environmental conditions over time, resulting in increased asset damage and failure from increase quantity or/and severity of cyclones, storms, lightning activity, dust storms, and droughts.

These factors impact uniquely on the Power and Water network and assets.

Table 13: Environmental challenges in relation to distribution substation asset management

Region	Environment	Challenges	Expenditure / risk implications
Alice Springs	Desert	• Dust storms and drought • Occasional flooding after long dry periods.	• Hot desert environment leading to heat related stresses and reduced productivity • Although rare, extreme weather events do occur (eg. flooding) • Aggressive soil types resulting in high corrosion issues (particularly related to steel assets, eg. earthing systems, poles) • Climatic change may result in increased asset damage and failure from increase quantity or/and severity of dust storms and drought • No immediate distribution substation investment programs planned

Region	Environment	Challenges	Expenditure / risk implications
Darwin	Coastal / Tropical	• Cyclones • Up to 21,924 lightning strikes per year (Global Position And Tracking Systems (GPATS) - 2007 to 2017 Data) • 6-8 Ground strikes per km^2 per year (Bureau of Meteorology (BOM)) • Tropical storms with winds in excess of 100 kilometres per hour • Long periods of high supply demands • High corrosion rates	• Hot and humid environment leading to heat related stresses and reduced productivity • Extreme weather events (eg. cyclones, flooding) • Increased asset damage and failure from increased quantity or/and severity of storms and lightning related to climate change • Increased distribution substation damage and failure from increased quantity or/and severity of storms and lightning • SPUDS replacement/refurbishment program
Katherine	Desert / Tropical	• Dust storms and drought • Tropical storms	• Hot and humid environment leading to heat related stresses and reduced productivity • Increased asset damage and failure from increases quantity or/and severity of storms and lightning related to climate change • No immediate distribution substation investment programs planned
Tenant Creek	Desert	• Dust storms and drought • Occasional flooding after long dry periods.	• Hot desert environment leading to heat related stresses and reduced productivity • Increased asset damage and failure from increase quantity or/and severity of dust storms and drought related to climate change • No immediate distribution substation investment programs planned

6.2 Operational challenges

1) Asset access

Unpredictable weather conditions and extended and high rainfall periods limit the ability to access assets and effectively schedule and undertake operational and construction activities during the wet season. This directly impacts on productivity associated with civil and structural works due to ground water levels filling excavations, impacting excavation wall integrity, and distribution substation installations in extreme conditions that can affect workmanship due to both water ingress and the physical stress on field crews. This is exacerbated by the majority of distribution substation faults occurring during the worst working conditions, as shown in Figure 20.

2) Asset design and maintenance

The impact from animals on ground based and overhead assets cannot be understated. Animals including a range of bird species, rodents, bats and termites all add to a reduction in reliability within the network. Through design considerations and condition based monitoring some of the issues are being resolved.

Further investigations into the potential screening or covering of assets where practical are underway.

3) System planning

A key system planning challenge relates to forced outages to allow for the operation of tap changers at distribution substations to maintain quality of supply standards. Operational changes to the network have been made such that these voltage level challenges have been reduced substantially. The success is currently being monitored and further adjustments will be made if so required.

4) Operational effectiveness

Power and Water operates in hot and humid environments leading to heat related stresses and reduced productivity resulting in increased time to undertake maintenance and inspection tasks. These 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 in selected locations across Australia.

Workability is the term used to 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 14 describes the work rates used in the study along with a description and examples.

Table 14 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 trenches, hauling cables, moving cable, pillars, poles

The outcome of the study is shown in Table 15 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 15 Workability for selected Australian locations based upon moderate metabolic rate

Location	Month											
	J	F	M	A	M	J	J	A	S	O	N	D

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) Demand profile

The demand profile across the network is flat and consistent across each day, as shown in Figure 18. The daily peak is fairly flat and consistent between 8am and 10pm, and is driven by the use of air conditioners. This shows that all assets are utilised consistently and therefore it is more difficult to remove assets from service for prolonged periods of time.

During the wet season, November to April, the load profile becomes flatter (more consistent) with less difference between the peak and the trough and the demand is about 10% higher.

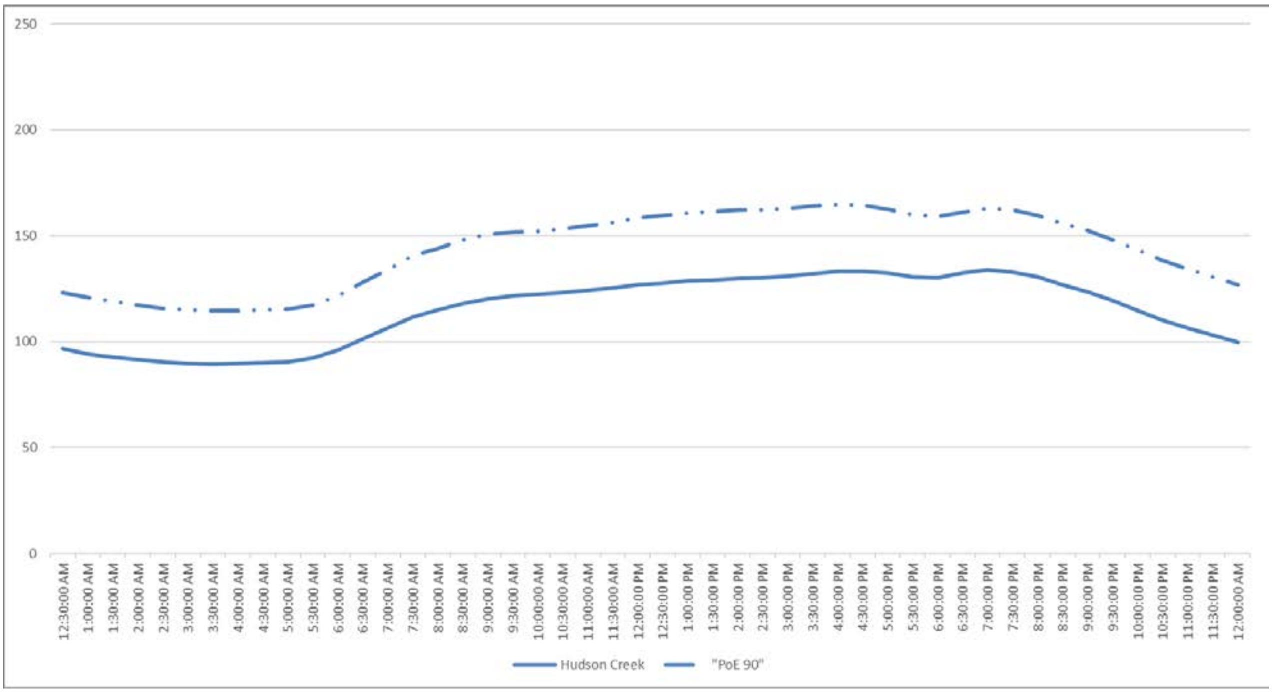

Figure 18 Darwin average daily demand profile (Hudson Creek ZSS) May to October

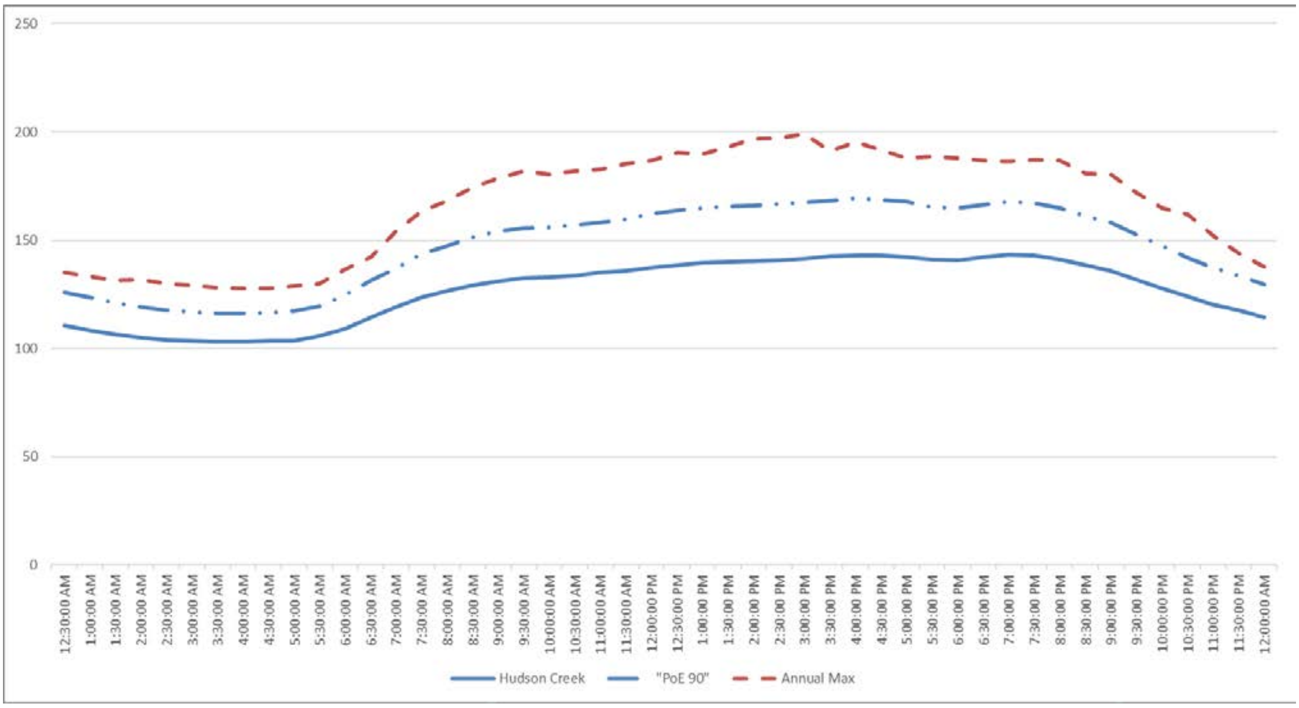

Figure 19 Darwin average daily demand profile (Hudson Creek ZSS) November to April

The annual maximum shows the demand for the highest half hour interval for the year. This shows that although the average peak was approximately 150 MVA, the maximum was 200 MVA, or 33% higher.

6) Seasonal challenges

Darwin has two distinct seasons, the 'wet' and the 'dry'. The wet season runs from November until April, and is characterised by high humidity, monsoonal rains, and storms. Temperatures typically range from a minimum of 20°C to a maximum of 33°C[3] as measured by the Bureau of Meteorology (BOM) over a 77 year period from 1941.

Figure 20 shows the 10 year average monthly maximum temperature measured in Darwin indicating the change in season during the year, in comparison with the corresponding average number of distribution substation failures. The ‘dry’ season is characterised by average maximum temperatures dropping to around 31°C and the ‘wet’ season with average maximum temperatures up around 34°C.

The distribution substation failure profile shows a strong correlation between distribution substation failures and the seasonal climate conditions. An increase in asset failures is observed during the time periods when environmental factors, access to assets, workability, and demand profiles presents the highest challenges.

As climate conditions continue to change a corresponding increase in distribution substation failures are expected to be observed during these worst periods of the year, and especially impacting the Darwin region at the Top End of the Northern Territory.

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[3] Bureau of Meteorology (BOM), Climate statistics for Australian locations, Darwin

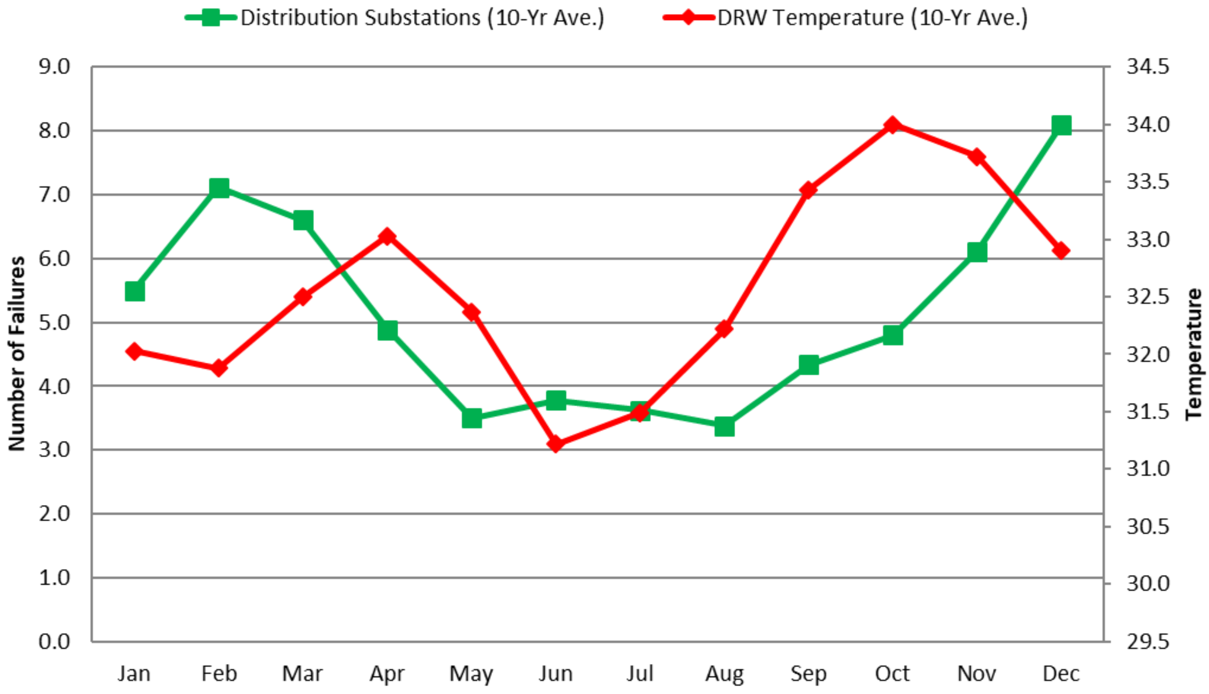

Figure 20: Average annual temperature and distribution substation failure profile

6.3 Asset challenges

The key underlying asset challenges associated with distribution substations are corrosion and oil leaks, particularly in the Darwin region were the assets are subject to high corrosion environments.

The asset challenges have been grouped into overhead installations and ground based installations as listed below, and particular investment programs addressing key asset challenges have been extracted.

1) Package or kiosk type installations and Ground mounted Distribution Substations

For package type installations there were 32 failures in the last 20 years with 4 failures in the past financial year. These failures are mainly winding related brought on from severe weather conditions. It is challenging to mitigate these failures as they are initiated by external factors. Even so and to improve Power and Water's understanding of these failures, Power and Water performs analysis on failed equipment to assess cause and potential mitigating actions.

By far the greatest challenge faced by Power and Water is that of corrosion of the transformer body and/or gaskets which eventually leads to oil leaks and ultimately to transformer failure. These leaks occur at bushing gaskets, oil sight glass gaskets or at the base of the transformer due to corrosion. Condition assessments are undertaken and where identified the impact from gasket failure and corrosion are identified and where possible rectified. If maintenance costs exceed that of replacement costs, the transformer will be replaced.

For older package type installations where paper lead cable terminations are used there have been regular instances where the crossing over of cable terminations creates partial discharge between phases. The only workable solution is to change the termination to single core XLPE cable rather than the multi-core paper lead cable. This is however costly due to the associated excavation costs.

2) SPUDS

Full details on this asset challenge are available in the BNI document:

- NMP17 - Single Phase Substation Replacement/Refurbishment

The single phase substation network is unique to Australia and includes 322, 6.35 kV, SPUDS in Darwin’s urban area. The majority of the substations were installed over a 4 year period from 1980 to 1983 and the portfolio has a weighted average age of 34 years. Given a typical operational life of 45 years, the average remaining life of the single phase substation population is approximately 11 years.

Corrosion at the bottom of transformer tanks is the most common failure mode. The SPUDS are mostly located in the front yards of residential properties and subject to watering and build-up of dirt, leaves, etc. The installation and environmental conditions maintain moisture beneath the tank and accelerates the corrosion of the base of the substation. As the corrosion is not visible, oil leaks develop over time, contaminating soil around the substation, and if undetected ultimately leads to internal flashover.

Electrical failure due to loss of insulating oil places people in proximity to the substation at risk. Containment of fault energy cannot be guaranteed and being a residential area, the likelihood of people being present during a failure event is elevated.

Operationally, any maintenance and fault conditions result in an excessive performance and cost impact, since there is no ability to transfer loads between substations in the SPUDS network and therefore generators are required in all cases to maintain customer supply in the event of a failure or maintenance. SPUDS contributed around 2% to Darwin’s annual system fault events in recent years.

A targeted replacement and refurbishment program to rectify corrosion defects and bring high risk SPUDS back to acceptable design standards are proposed.

3) Pole Mounted Distribution Substations

For pole mounted type installations there were 158 failures in the last 20 years with 8 failures in past financial year. These failures are mainly winding related brought on from severe weather conditions and difficult to mitigate.

By far the greatest challenged faced by Power and Water is that of corrosion of the transformer body and/or gaskets leading to oil leaks and ultimately functional failure. These leaks typically occur at the bushing gaskets, oil sight glass gaskets or at the base of the transformer due to corrosion. Other areas where failures have been recorded include broken HV tails, LV termination failures, HV EDO fuse assembly failure and surge arrestor failures.

Similar to ground mounted distribution substations forced outages have been required to accommodate the need for tap changers to be operated, brought on from voltage levels requiring support to maintain quality standards. However operational changes to the network have been made such that these voltage level challenges reduced substantially.

For both ground and pole mounted distribution substations, Power and Water is acquiring an emerging understanding of risks around earthing for substations. This is necessary due to theft of ground wires as well as earthing not being installed adequately in the past. It is projected with improved understanding of earthing properties and installation throughout the network, additional capital expenditure will be allocated towards the issues surrounding earthing.

6.4 Asset Management challenges

Asset management is the application of management, financial, economic, engineering and other practices to infrastructure assets with the objective of providing the required level of service in the most cost-effective manner. It requires the management of the asset condition throughout the asset life cycle, including design, construction, commissioning, operating, maintaining, repairing, modifying, replacing and decommissioning/disposal. A study of condition and performance data captured over time assists in managing the asset to function optimally in a safe and reliable manner throughout its life cycle. The life cycle asset management approach applied by Power Networks is provided in Appendix A.

A key asset management challenge is a lack of comprehensive asset condition assessment data across the network to fully understand and evaluate the health and deterioration of the distribution substation assets.

Improvement in the processes for and quality of data collection is a key focus and is being prioritised. Significant steps have already been taken through the introduction of mobile devices to capture data in the field at the time of inspection and testing. The impact of corrosion deterioration on the functional integrity and strength of distribution substations are also being investigated through post failure assessments and testing.

7 Performance indicators

The performance of distribution substations against the specific objectives and measures identified in section 2.3 are provided here. The performance shown here represents the historical performance of the asset class to date. It is expected that benefits from investments proposed in the next regulatory period will manifest as benefits in these key objectives. The projected investment outcomes in relation to past performance trends are provided in section 11.

7.1 Operational performance indicators

The performance of the distribution substation asset class over the 10 year period from 2006/2007 is provided in Figure 21 and includes ground mounted, package/kiosk, and pole mounted substations. The charts show the performance based on sustained outages only, i.e. outages with a duration greater than 1 minute, and exclude major event days (MEDs). In particular, the following events were excluded from the analysis, in calculating the % contribution of the asset class into NT SAIDI/SAIFI:

a) Planned outages
b) Generation-related outages
c) Outages that were internal to customer premises
d) Outages initiated in the interest of public safety

The distribution substation contribution to NT system SAIDI under a 'no investment' scenario indicates a relative small, less than 0.5%, increase in contribution over the regulatory period bringing the expected total contribution by 2023/24 to around 4.2%, a corresponding 2% increase in SAIFI contribution up to a total contribution of around 5.5% is projected.

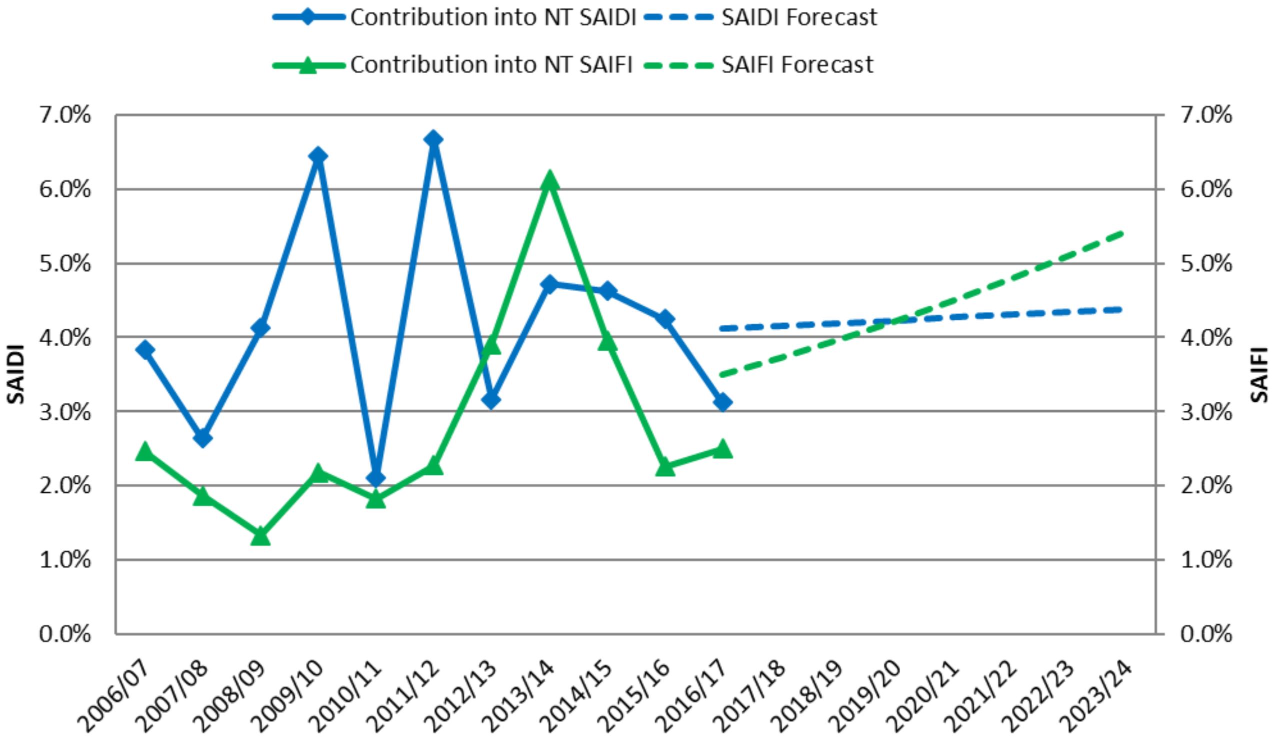

Figure 21: Distribution substation asset class contribution into SAIDI/SAIFI

7.2 Health and Safety indicators

A key corporate objective is the safe operation of the network. The number of safety related events associated with distribution substations as recorded over the last 10 years is shown in Table 16. Safety-related incidents include those outages caused by third party impacts with Power and Water assets, public and worker safety-related outages, and forced outage requested by emergency services.

Table 16: Number of safety-related incidents associated with distribution substations

Financial Year	Number of Outages	Comment
2006/07	2	Incident - Third Party
2007/08	1	Incident - Third Party
2008/09	2	Incident - Third Party
2011/12	1	Incident - Third Party
2012/13	1	Incident - Third Party
	3	Forced outage - Power and Water equipment presents unacceptable risk
	6	Outage in the interest of Power and Water worker safety
2013/14	5	Forced outage - Power and Water equipment presents unacceptable risk
	7	Outage in the interest of Power and Water worker safety
2014/15	2	Incident - Third Party

Financial Year	Number of Outages	Comment
	3	Forced outage - Power and Water equipment presents unacceptable risk
	8	Outage in the interest of Power and Water worker safety
2015/16	2	Incident - Third Party
	6	Forced outage - Power and Water equipment presents unacceptable risk
	2	Outage in the interest of Power and Water worker safety
2016/17	12	Forced outage - Power and Water equipment presents unacceptable risk
2006/07	1	Incident - Third Party
Total	**64**	

7.3 Financial indicators

Power and Water's long term financial sustainability as underwritten by affordable service and shareholder returns is demonstrated in the efficient and competitiveness of its capital and operating costs.

The capital expenditure forecast for distribution substation assets has been based on historical unit costs, relying on recent and similarly scoped projects. The approach aligns with industry best practice and relies on data that is continuously validated and updated.

7.3.1 Capital unit costs

The capital unit rates are a significant input towards the capital expenditure forecast and have been calculated and justified to be as efficient and prudent.

The capital unit rates applied in establishing the regulatory capital forecast, have been assessed against similar unit costs observed across the National Electricity Market (NEM). The comparison provided an indicative measure of the reasonableness of Power and Water's costs and has been based on publicly available data sourced from the Australian Energy Regulator's (AER's) Repex modelling and utility Regulatory Information Notice (RIN) submissions.

There are a number of internal and external operational, asset type, and environmental factors that influence the benchmark costs and provide a challenge in respect of the ability to undertake accurate comparisons. Normalisation for these factors has not been undertaken and the benchmark comparisons provided are an indicative measure of reasonableness only.

The single phase substation network is unique and not many of the utilities that would typically be considered comparable with Power Networks has similar package/kiosk type single phase substation installations. A comparison was therefore made against the unit costs of those utilities across the NEM that does have equivalent installations. These utilities included CitiPower, Powercor, SA Power Networks, and United Energy.

Where historical unit costs have been utilised as part of the bottom-up estimates or historical analysis, these have been escalated to 2017/18 dollars by CPI only. The CPI escalation factor was derived from indexes published by the Australian Bureau of Statistics for all consumer groups and applicable to the Darwin area.

Power and Water's unit cost for the replacement of distribution substations are provided in Figure 22. In comparison with peer averages observed across the NEM Power and Water's costs are at the upper range of costs, however are not considered and outlier. The higher costs are reflective of the unique installation requiring additional equipment and resourcing to maintain power supply during replacement works. This asset challenge is compounded by the harsh weather conditions, and a tropical climate that impacts on the productivity of work undertaken in the Northern Territory.

Taking into consideration the extenuating network design and work conditions, the unit costs are considered reasonable.

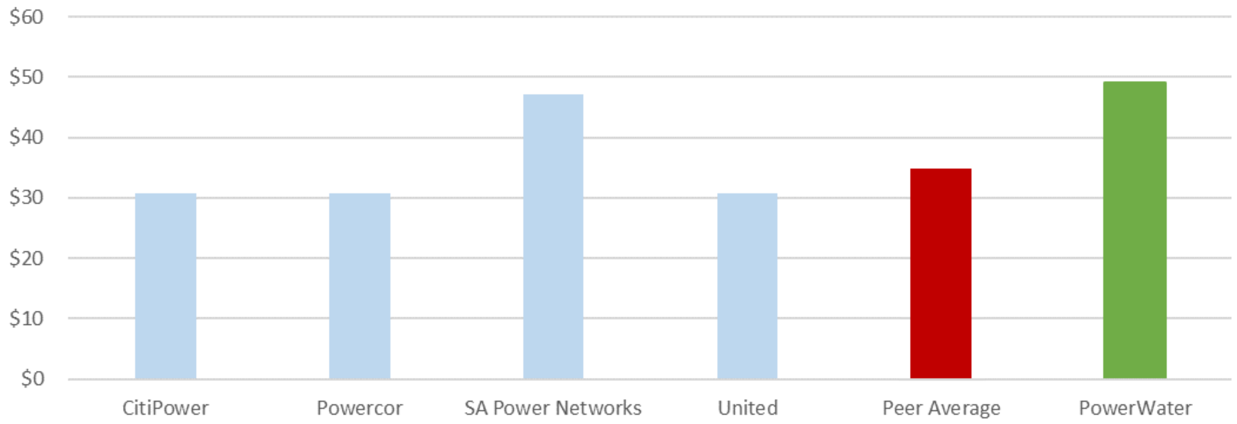

Figure 22: Single Phase Substation Replacement Unit cost comparison

7.3.2 Operating unit costs

The operational expenditures include that expenditure incurred in operating and managing the distribution substation assets, ensuring that the assets continue to provide their pre-determined service capacity and quality of service and achieves their useful life. The operating expenditure therefore includes maintenance and direct overhead expenditure associated with the distribution network.

Maintenance expenditure includes those costs incurred when:

- an asset is restored to its operational condition, and
- to ensure the asset meets its operational performance, reliability, and
- does not extend the useful life of the asset.

Direct overhead expenditure is expenditure associated with scheduling and planning. These support activities cannot readily be identified as belonging to a particular value adding task/activity and has been allocated on a pro-rata basis.

Similar to the capital cost, a comparison with peer utility expenditures has been applied to provide an indicative measure of the reasonableness of Power and Water's costs and has been based on publicly available data sourced from the utility Regulatory Information Notice (RIN) submissions.

Insufficient peer utility data was available to allow for a comparison of operations and maintenance costs associated with emergency response works at the asset class level. Emergency response operation and maintenance costs have therefore been excluded from the comparison.

There are internal and external operational, asset type, and environmental factors that influence the benchmark costs and provide a challenge in respect of the ability to undertake accurate comparisons. Normalisation for these factors has not been undertaken and the benchmark comparisons provided here are an indicative measure of reasonableness only.

Where historical unit costs have been utilised as part of the analysis, these have been escalated to 2017 dollars by CPI only. The CPI escalation factor was derived from indexes published by the Australian Bureau of Statistics for all consumer groups and applicable to the Darwin area.

A comparison of Power and Water's average annual routine and non-routine maintenance cost in comparison with peer organisations are provided in Figure 23. The Power and Water cost represents the average annual cost recorded over the last 5 years.

The high level unnormalized comparison indicates that Power and Water's operating cost is high in relation to costs recorded across the NEM. This is reflective of historical routine maintenance frequencies, overhead non-trades labour cost allocations, and capitalisation practices. Historically annual inspections were undertaken contributing to a higher annual routine maintenance cost, this has now been amended to 3 yearly inspections and are expected to reduce routine maintenance costs going forward. An under recovery of capitalisation costs are currently being reviewed. Improvements in the capitalisation of costs associated with asset replacements are expected to result in material reductions in repair and maintenance costs. Direct overhead costs associated with planning, scheduling, and asset management are included in the maintenance costs. This contributes up to 65% of the total repair and maintenance expenditure. Changes in this practice are not expected in near future and will continue to elevate repair and maintenance costs.

Power Networks operate in an environment characterised by extreme temperatures, high humidity, heavy and extensive rainfall, high corrosion zones and aggressive soil types present unique challenges for managing the assets. These challenges require Power Networks to employ methodical inspection and maintenance practices to sustain the asset condition. These practices include the careful scrutiny, cleaning, testing, and rectification of equipment defects and abnormalities, for example the replacement of multi core paper lead cable ends in package substations with single core XLPE cable ends to mitigate against cables crossing over and creating partial discharge between phases. The systematic maintenance requirements combined with harsh weather conditions that effect the productivity that can be achieved during normal work hours, contributes to the expected higher cost of routine and non-routine maintenance activities.

Power and Water's historical routine and non-routine maintenance costs associated with distribution substations are considered relatively high, but within reason given the differentiating historical maintenance cycles and practices and the extenuating work environment.

Future expenditures are expected to benefit from improved capitalisation practices and changed maintenance cycles. These benefits have not been included in this reasonableness test.

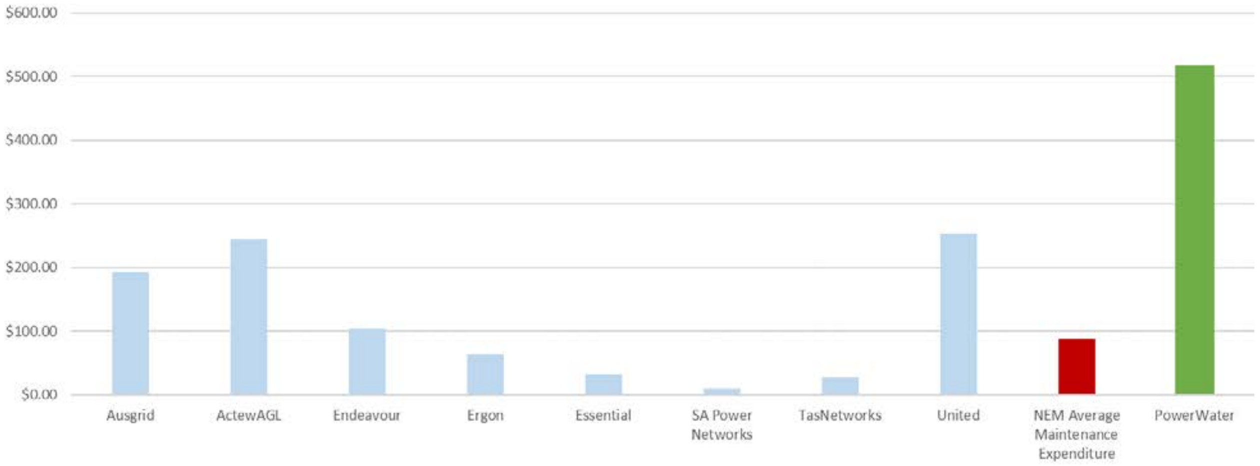

Figure 23: Distribution substation routine and non-routine maintenance cost comparison

8 Growth requirements

The demand for power infrastructure is driven mostly by growth in the number of new network connections. To understand this potential growth Power and Water engaged AEMO in 2017 to undertake a connection forecast for the network regions of Darwin-Katherine, Tennant Creek, and Alice Springs[4]. The study outcome identified relative low customer connection growth across the network with the highest expected average growth in Tennant Creek, 1.0% followed by Darwin, 0.8% and Alice Springs, 0.1%. The outcome of the connection forecast is summarised in Figure 24.

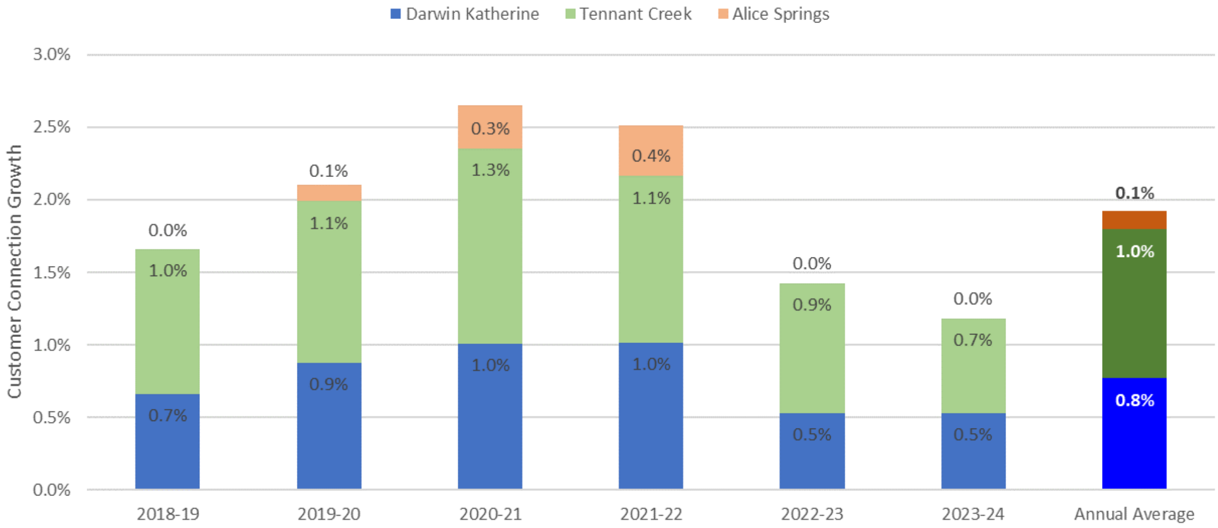

Figure 24: Customer connection growth by region (AEMO 2017 Forecast)

Distribution substations transform high voltages to low voltages for customer connections, making the projected connection growth a very reasonable proxy for the expected increase in distribution substation asset requirements over the same period.

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[4] AEMO, Power and Water Maximum Demand, Energy Consumption, and Connections Forecast, September 2017

It is noted that the AEMO connection growth forecast shows a significantly reduced growth rate in comparison with Power and Water's annual average growth in distribution substation assets over the recent 5 years from 2012/13 to 2015/16, as shown in Table 17. The changing environment with reducing demand growth is expected to impact on the requirement for network growth. The AEMO forecast has been adopted to project the expected growth in distribution substation assets by the end of the regulatory period, 2023/24.

The projected increase in distribution substation assets are provided in Table 17. In summary the following approach was taken in doing the asset growth projections:

- The forecast was based on the customer connection forecasts from AEMO's 2017 report: *Power and Water Corporation Maximum Demand, Energy Consumption, and Connections Forecasts.*
- The current asset base (i.e. number of distribution substations) were increased each year according to percentage change in the forecast number of connections.
- For periods where this percentage change was negative, the asset base remained the same, under the assumption that the existing network size will not reduce as result of short-to-medium term negative customer growth.

Table 17: Distirbution substation forecast growth, qty (FY19 to FY24)

Region	Historical average annual asset growth rate (2013/14 to 2016/17)	AEMO annual connection growth rate	Distribution substation increase by 2023/24
Darwin-Katherine	2.8%	0.8%	191
Alice Springs	1.3%	0.1%	5
Tennant Creek	1.6%	1.0%	9
Total distribution substation increase	**2.6%**	**0.7%**	**205**

The growth in assets will impact on the health and criticality profile of the asset class. The new assets are expected to be of good health with a pro-rata spread across the asset criticalities.

The revised forecast health and criticality profiles for distribution substations by the end of the regulatory period, assuming no investment and including growth are shown in Table 18. The growth numbers are reflected in the increase in the H1 asset quantities.

Table 18: Distribution substation health-criticality matrix (qty) with growth and no investment

	H1	H2	H3
C1	3,124	142	359
C2	845	146	112
C3	167	48	71

9 Renewal and maintenance requirements

Power and Water's renewal and maintenance investment plans are aimed at addressing key asset challenges identified within the asset class.

Targeted inspection and testing are undertaken to investigate assets of concern, and a targeted assessment applying the asset health and criticality decision making approach[5] and the more detailed understanding of the condition of the specific assets is used to assess the risk associated with the assets to identify those assets that bears the greater risk.

Opportunities to maintain the safe and reliable operation of the network are then considered and this typically includes assessing options of run-to-failure, test and replace, and targeted pro-active renewal. The outcomes of the assessment manifests in a preferred investment option with a high level scope and cost estimate.

Maintenance activities are crucial in the early identification of asset health and condition issues and the prioritisation of assets for further investigation. Inspection findings, field service feedback, and performance measures are the main inputs used to identify those assets that are of particular concern, or may have a type issue. Routine asset inspections are therefore a fundamental aspect of Power and Water's maintenance regime to ensure prudent and effective investments.

The process and outcomes of the renewal and maintenance requirement assessments are documented in the Business Needs Identification (BNI) documents that are prepared for and approved by the Chief Executive.

The following projects and programs have been evaluated and provide the distribution substation renewal and maintenance requirements proposed for the next regulatory period.

9.1 Single Phase Underground Distribution Substations

9.1.1 SPUDS asset renewal plans

Full details on this asset challenge and assessment are available in the BNI document:

- NMP17 - Single Phase Substation Replacement/Refurbishment

Applying the health and criticality criteria laid out in section 5.1.3 the assessment of the SPUDS is provided in Table 19. It prioritises 61 SPUDS in the red and orange zones, and identifies a further 234 of poor health.

Table 19: SPUDS health-criticality matrix (qty)

	H1	H2	H3
C1	18	3	234
C2	4	1	50
C3	1		11

The projected annual replacement volumes over the regulatory period is provided in Table 20 and will replace 9 SPUDS and refurbish a further 198 targeting those assets identified in the red and orange zone, and continuing with those assets of poor health. This replacement program is expected to be continued in following regulatory periods.

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[5] 'Program Replacement Volume Forecast Method' discussion paper

Table 20: SPUDS renewals (qty)

Program	2019-20 Qty	2020-21 Qty	2021-22 Qty	2022-23 Qty	2023-24 Qty	Total Qty
Replacement volumes	1	2	2	2	2	9
Refurbishment volumes	18	33	47	53	47	198
Total renewal volumes	**19**	**35**	**49**	**55**	**49**	**207**

9.1.2 SPUDS asset maintenance plans

The maintenance plan for distribution substations is to continue with the established maintenance regime, which is based on 3-yearly inspections and repair (or replacement) upon failure. Inspections typically involve a ground based assessment of condition. Asset defects are prioritised based on risk of failure and included in the maintenance and defect rectification program.

Defects that cannot be identified through visual inspection eventually result in failure of the asset and are repaired or replaced under the pooled asset replacement program.

9.2 Distribution Substations

9.2.1 Distribution substation pooled asset replacements

Full details of this program evaluation are available in the document:

- 2019-24 Pooled Asset Replacement Forecasting Model Methodology

The pooled program captures those distribution substation assets that fail in service. These replacements are typically done under emergency conditions and are therefore of limited scope and cost, however impacts positively on the overall health of the network moving assets out of the poor health category. These failures are expected to be mostly associated with poor health and low criticality assets, i.e. those assets that are of poor health but not necessarily part a proactive replacement program.

The expected distribution substation replacements under this program have been projected using a probabilistic approach. The approach forecasts asset failures using a combination of asset age, asset conditional probability of failure, and historical asset failures. A total of 667 distribution substation replacements are forecast from 2017/18 to the end of the next regulatory period. The projected annual replacement volumes are provided in Table 21.

Table 21: Projected pooled distribution substation replacement volumes

Program	2017-18 Qty	2018-19 Qty	2019-20 Qty	2020-21 Qty	2021-22 Qty	2022-23 Qty	2023-24 Qty	Total Qty
Pooled distribution substation replacement volume	119	100	90	87	87	90	93	667

The health and criticality assessment of the distribution substation assets expected to be replaced through the pooled replacement program is shown in Table 22.

Table 22: Pooled program distribution substation health-criticality matrix (qty)

	H1	H2	H3
C1		85	213
C2		196	62
C3		50	60

9.2.2 HV distribution substation asset maintenance plans

The maintenance plan for distribution substations is to continue with the established maintenance regime, which is based on 3-yearly inspections and repair (or replacement) upon failure. Inspections typically involve a ground based visual assessment of condition. Asset defects are prioritised based on risk of failure and included in the maintenance and defect rectification program.

Defects that cannot be identified through visual inspection eventually result in failure of the asset and are repaired or replaced under the pooled asset replacement program.

10 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.

10.1Augmentation expenditure (augex)

The augmentation requirements for the distribution substation assets follows on a relative low connection growth forecast in most existing distribution areas. Power and Water engaged AEMO in 2017 to undertake a demand growth forecast for the network areas. The study identified relative low customer connection growth across the network with the highest expected average growth in Tennant Creek, 1.0% followed by Darwin, 0.8% and Alice Springs, 0.1%. The outcome of the connection forecast is discussed in section 8. Pocketed areas of growth is expected in areas of Darwin.

This changing environment with reducing demand growth is decreasing the need for capital investment on augmentation of distribution substations. Where growth is slow, network, non-network, and demand side management support options assist in managing load at risk.

Other drivers of augmentation expenditure include fault level and power quality limitations.

Several package substations have been identified which contain switchgear operating above its rated fault level capacity. A program to replace the 27 affected units has is proposed for the next regulatory period. Full details of this program evaluation are available in the BNI document:

- NMP7 Replacement of Distribution Substations due to fault levels

An ongoing power quality improvement program has been proposed to address power quality limitations as they arise. Typically this involves the upgrade of distribution transformers or other network segments. Full details of this program evaluation are available in the document:

- NPQ Power quality compliance program

The augmentation expenditure forecast for the above programs are provided in Table 23. It should be noted that not all expenditure in these programs relates to the distribution substation asset class.

Table 23: Augmentation expenditure forecast

Program	2019-20 ($ million)	2020-21 ($ million)	2021-22 ($ million)	2022-23 ($ million)	2023-24 ($ million)	Total ($ million)
Replacement of Distribution Substations due to fault levels	$1.08	$1.06	$0.88	$0.83	$0.80	$4.64
Power quality compliance program	$0.60	$0.60	$0.60	$0.60	$0.60	$3.00
Total Renewal	**$1.68**	**$1.66**	**$1.48**	**$1.43**	**$1.40**	**$7.64**

10.2Renewal expenditure (repex)

There are two renewal programs proposed for the asset class over the next regulatory period, 2019/20 to 2023/24. The programs are expected to cost $16.66 m over the 5-year period and include investment mainly in SPUDS and in assets that fail in service.

The renewal expenditure forecast based on the mention programs are provided in Table 24.

Table 24: Renewal expenditure forecast

Program	2019-20 ($ million)	2020-21 ($ million)	2021-22 ($ million)	2022-23 ($ million)	2023-24 ($ million)	Total ($ million)
SPUDS Replacement and Refurbishment program	$0.20	$0.38	$0.50	$0.55	$0.50	$2.13
Distribution substation pooled asset replacements	$2.71	$2.78	$2.89	$3.01	$3.14	$14.53
Total Renewal	**$2.91**	**$3.16**	**$3.39**	**$3.56**	**$3.64**	**$16.66**

The revised five-year forecast health and criticality profiles for the distribution substation asset class following the proposed investments are shown from Table 25. The reduction in risk is demonstrated in the number of assets that move from the poor health, H3 category to the good health category, H1 in comparison with the 'current' and 'no investment' risk scenarios provided in section 5.1.3.

Table 25: Distribution substation health-criticality matrix (qty) with investment

	H1	H2	H3
C1	3,418	207	🟨
C2	1,100	3	🟧
C3	284	3	🟥

10.3 Historic, forecast and future expenditure comparison

Historic replacement expenditure on distribution substations has been predominantly to address conditional and functional failures discussed in Section 6.3.

As outlined in the preceding sections, the forecast expenditure on distribution substations is targeted to address the key asset challenges expected to manifest over the regulatory period. It is noted that the forecast gradually increases over the course of the regulatory period, consistent with the expected rate of detection of corrosion and oil leaks on SPUDS.

Future expenditure in the asset class has been forecast using the AER's repex model and shows a steady rate of investment required in distribution substations. Whilst the AER's repex model is age-based model, Power and Water's approach is to target those assets in poor condition. It is expected that future investment in the asset class can be managed at a level below $4 million per annum.

10.4Operational expenditure (opex)

The operating expenditure for Distribution Substations for the next regulatory period is provided in Table 26

Table 26: 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)
Ground mounted distribution substations	Routine	$0.64	$0.29	$0.21	$0.47	$0.33	$0.31	$0.28	$0.28	$0.28	$0.28	$0.28
	Non-routine	$0.49	$0.46	$0.23	$0.56	$0.43	$0.38	$0.34	$0.34	$0.34	$0.34	$0.34
	Fault and emergency	$0.01	$0.36	$0.03	$0.12	$0.12	$0.12	$0.12	$0.12	$0.12	$0.12	$0.12
Total		**$1.14**	**$1.11**	**$0.47**	**$1.14**	**$0.88**	**$0.81**	**$0.74**	**$0.74**	**$0.74**	**$0.74**	**$0.74**
Package distribution substations	Routine	$0.14	$0.03	$0.24	$0.06	$0.10	$0.09	$0.08	$0.08	$0.08	$0.08	$0.08
	Non-routine	$0.88	$1.00	$0.82	$1.22	$0.97	$0.87	$0.77	$0.77	$0.77	$0.77	$0.77
	Fault and emergency	$0.25	$0.20	$0.54	$0.58	$0.36	$0.35	$0.34	$0.34	$0.34	$0.34	$0.34
Total		**$1.26**	**$1.22**	**$1.60**	**$1.87**	**$1.42**	**$1.31**	**$1.20**	**$1.20**	**$1.20**	**$1.20**	**$1.20**
Pole mounted distribution substations	Routine	$0.00	$0.03	$0.02	$0.04	$0.02	$0.02	$0.02	$0.02	$0.02	$0.02	$0.02
	Non-routine	$0.26	$0.50	$0.44	$0.37	$0.38	$0.35	$0.31	$0.31	$0.31	$0.31	$0.31
	Fault and emergency	$0.38	$0.25	$0.47	$0.28	$0.32	$0.31	$0.30	$0.30	$0.30	$0.30	$0.30
Total		**$0.64**	**$0.78**	**$0.93**	**$0.69**	**$0.72**	**$0.67**	**$0.63**	**$0.63**	**$0.63**	**$0.63**	**$0.63**
All distribution substations	Routine	$0.78	$0.35	$0.47	$0.57	$0.45	$0.42	$0.38	$0.38	$0.38	$0.38	$0.38
	Non-routine	$1.63	$1.96	$1.49	$2.15	$1.78	$1.60	$1.42	$1.42	$1.42	$1.42	$1.42
	Fault and emergency	$0.64	$0.81	$1.04	$0.98	$0.80	$0.78	$0.76	$0.76	$0.76	$0.76	$0.76
Total		**$3.04**	**$3.11**	**$3.00**	**$3.70**	**$3.02**	**$2.79**	**$2.57**	**$2.57**	**$2.57**	**$2.57**	**$2.57**

11 Asset class outcomes

11.1 Key performance indicators

11.1.1 Reliability indicators

Investments in the distribution substation assets are expected to impact on the performance of the asset class, and the contributions made into the system SAIDI/SAIFI performance. The contribution from each investment program was analysed to identify the potential improvements that could be affected.

Improvements were calculated as the percentage contribution to total system performance at an asset level based on historical performance and taking into account existing asset quantities, expected growth rates, and renewal volumes. The SAIDI/SAIFI improvements followed the quantity of assets expected to be replaced or refurbished. The expected benefit in SAIDI and SAIFI contribution is provided in Figure 25.

An improvement of around 0.7% in SAIDI performance by 2023/24 is projected and similarly, a reduction in system SAIFI contribution of around 0.8% is projected by the end of the regulatory period.

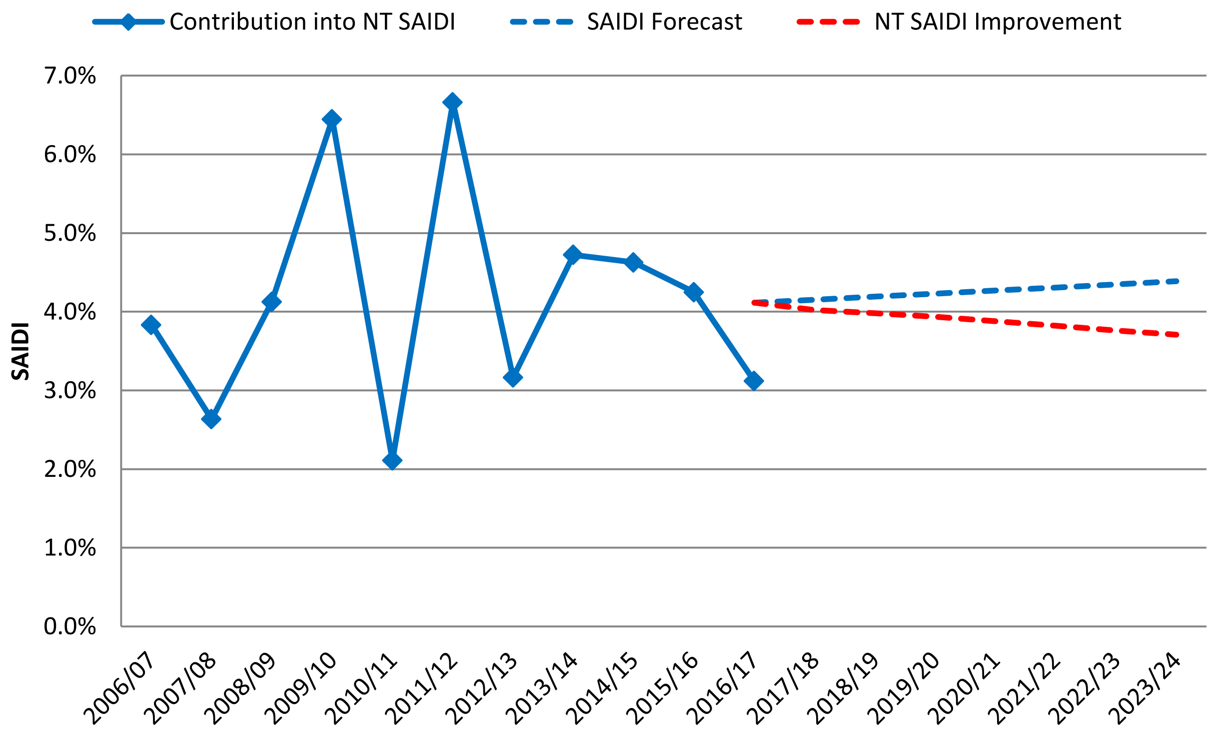

Figure 25: Distribution substation contribution into SAIDI following investment

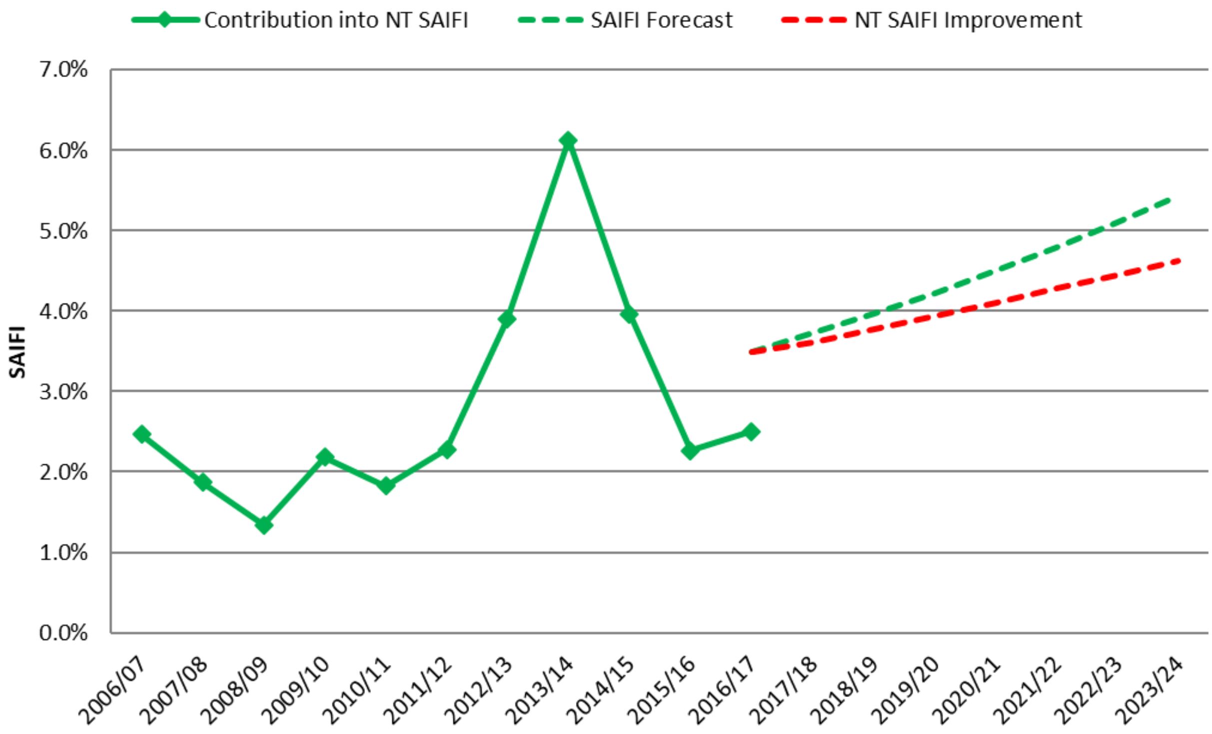

Figure 26: Distribution substation contribution into SAIFI following investment

11.1.2 Responsibility indicators

The number of safety related events associated with distribution substations are expected to be impacted by the proposed investment in SPUDS. Safety-related incidents includes those outages related to public and worker safety. These include forced outages to allow for the safe operation and maintenance of the network and contribute nearly half (45%) of the total number of safety related events on distribution substations.

The available data does not allow for a quantification of the SPUDS contribution, however internal switching components deterioration and damage has resulted in an increasing need for forced outages in recent years in the interest of Power and Water worker safety. These incidents are expected to reduce as result of the investment program.

12 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 distribution substation defect modes and trends. These insights provide for informed decision making on whether to repair or replace distribution substation assets. It assists in the continuous development of the asset management strategy for distribution substations.

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 with increased focused. Any improvements in analysis and understanding of the distribution substation fleet will be included in this AMP when it is updated.

The RACI model provided in section 3.1 identifies the roles and responsibilities important in the management of the distribution substation assets. These responsibilities include ongoing performance monitoring and strategy revisions.

13 Appendix A – Lifecycle asset management

Power and Water makes great efforts to ensure being 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 takes in managing its assets. The life cycle asset management approach applied 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 details Power and Water's life cycle management of its distribution substations and associated assets.

13.1 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.

Key criteria to ensure optimal line route selection, establishing prudent, cost efficient, intrinsically safe, and sustainable corridors for the life cycle management of the distribution substations include consideration of:

- Optimised utilisation of existing infrastructure
- 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

13.2 Design

The design phase is where decisions around the physical characteristics and functioning of the asset are 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 cycle prudent and efficient design of assets includes the standardisation of distribution substations and associated equipment. Standardisation is defined as the process of developing and agreeing on 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 distribution substation design standardisation offers the following specific benefits to the business. It:

- 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
- Boost production and productivity
- Encourages higher quality of engineering leveraging specialist knowledge and optimum solutions
- Allows for the uniform execution of projects
- Enables standardisation of construction equipment and processes

13.3 Operation

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

- Planned switching of the network for scheduled works (eg. maintenance)
- Emergency switching of the network in response to incidents (eg. fault events)
- Real time switching to operate the asset within its design parameters (eg. loading)
- Monitoring of the condition of the asset (eg. alarms)

Power and Water recognises the need to outline and communicate a single, coherent operating model with clear responsibilities across the full asset lifecycle of the distribution substations. To this end, key competencies required to operate the asset is always identified and adequate training provided. Power and Water works diligently to ensure that different business units of the organisation have clear roles and responsibilities for each asset category.

13.4 Maintenance (opex)

Asset maintenance involves the upkeep of assets to ensure they will function to their required capability in a safe and reliable manner from their commissioning to their disposal. This is achieved though the following maintenance objectives:

- maintain the functional performance of the assets
- identify potential problems before the condition of assets is compromised
- minimise damage to assets during faults
- avoid or limit the duration of customer supply interruptions
- enable a planned and structured approach to repair or replacement of assets

- reduce risk to personnel and public
- mitigate public liability risk

Maintenance requirements evolve as the condition and performance requirements of the assets change through its life. It monitors and provides feedback on asset condition, it incorporates upkeep and repair activities to maintain the condition of the asset, and it also 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 monitoring, upkeep and repair, testing and component replacements. Preventative maintenance expenditure increases over time as assets age.
- 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.
- 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 3 yearly ground based visual inspection cycle to assess the health of distribution transformers. The inspection involves a judgement of condition and risk of failure based on a visual assessment and in conjunction with system performance tracking provides a pointer to potential asset integrity issues. High risk assets are prioritised for further investigation and testing.

13.5 Renewal (repex)

Asset renewal is the establishment of a new asset in response to an existing asset’s 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 programs in place to renew assets of poor condition as close as possible yet prior to the asset failing.

13.6 Disposal

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

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

Power and Water ensures that all assets identified for disposal are disposed of in an environmentally responsible manner.