Distribution Transformers

AMS – Electricity Distribution Network

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Disclaimer

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1 Executive Summary

This document is part of the suite of Asset Management Strategies relating to AusNet Services' electricity distribution network. The purpose of this strategy is to outline the inspection, maintenance, replacement and monitoring activities identified for economic life cycle management of Distribution Transformers in AusNet Services' Victorian electricity distribution network.

This strategy is focused on 61,382 Distribution Transformer, operating at predominantly 12.7kV and 22kV and consisting of pole mounted types (92.6%) and ground mounted types (7.4%) consisting of indoor, outdoor pad mounted and kiosks.

Over the last few years there have been reduced distribution transformer failures resulting in lower community impact due to customer outages, bushfire and safety risks. The better performance is particularly due to past proactive planned replacements based on transformer loading measurements and condition based replacements.

Condition assessment shows that total transformer fleet is generally in "Good" condition (C1, C2 or C3) and a total of approximately 5.1% are either in "Poor" (C4) or "Very Poor" condition (C5).

Risk analysis based on condition and monetized consequence of failures show approximately 645 pole mounted and ground type distribution transformers over the next 2022-26 period should be targeted for replacement.

The summary of proposed asset strategies is listed below.

1.1 Asset Strategies

1.1.1 New Assets

- Procure distribution transformers to AusNet Services' specification DES 10-19 and AS 2347.
- Install distribution transformers to Standard Installation Manual 30-4142.
- Install pole mounted transformers on concrete poles in line with AMS 20-70.
- Install new surge arresters on all new and replacement transformer installations in line with AMS 20-67.
- Install fully insulated medium voltage connections to all new and replacement distribution transformer installations as per Standard Installation Manual 30-4142.

1.1.2 Inspection

- Inspect distribution transformers in accordance with the Asset Inspection Manual 30-4111.
- Review current inspection regime of ground mounted transformers : Indoor and Kiosk types
- Consider internal inspection and thermal scanning of approximately high risk 600 ground mounted transformers in the EDPR 2022-26 period.

1.1.3 Monitoring

- Use Advanced Meter Interval (AMI) 'smart meter' data to effectively monitor loading and utilisation of transformers identifying potential thermal overload issues.
- Perform targeted thermal monitoring, partial discharge and dissolved gas analysis on large capacity three-phase units, typically Kiosk, indoor and ground type installations.

1.1.4 Refurbishment

- Refurbish larger capacity three-phase units where operating losses and expected remaining service potential post refurbishment is economic compared with a new asset.

1.1.5 Replacement

- Replace-on-condition – Transformers where electrical utilisation exceeds 130% of nameplate rating.
- Replace-on-condition – Transformers where rust threatens the containment of insulating oils or where oil leaks threaten environmental pollution or transformer function.
- Replace-on-condition – Three-phase transformers where operating temperatures, partial discharge emissions or dissolved gasses threaten transformer functioning.
- Replace-on-failure – Transformers damaged by lightning or animal-initiated arcing faults or electrical overload.

2 Introduction

2.1 Purpose

The purpose of this document is to outline the inspection, maintenance, replacement and monitoring activities identified for economic life cycle management of distribution transformers in AusNet Services. This document is intended to be used to inform asset management decisions and communicate the basis for activities.

In addition, this document forms part of our Asset Management System for compliance with relevant standards and regulatory requirements. It is intended to demonstrate responsible asset management practices by outlining economically justified outcomes.

2.2 Scope

This Asset Management Strategy applies to all outdoor and indoor type distribution transformers, except station service transformers, connected to medium voltage distribution network of AusNet Services.

Zone substation station service transformers, are covered under AMS 20-80 Auxiliary Power Supplies.

2.3 Asset Management Objectives

As stated in *AMS 01-01 Asset Management System Overview*, the high-level asset management objectives are:

- Comply with legal and contractual obligations;
- Maintain safety;
- Be future ready;
- Maintain network performance at the lowest sustainable cost; and
- Meet customer needs.

As stated in *AMS 20-01 Electricity Distribution Network Asset Management Strategy*, the electricity distribution network objectives are:

- Improve efficiency of network investments;
- Maintain long-term network reliability;
- Implement REFCL's within prescribed timeframes;
- Reduce risks in highest bushfire risk areas;
- Achieve top quartile operational efficiency; and
- Prepare for changing network usage.

3 Asset Description

3.1 Asset Function

Distribution Transformers are required to convert electrical energy from medium voltages to low voltages in the AusNet Services electricity distribution network for electricity supply to customers.

Typically smaller size pole mounted distribution transformers supply power to a cluster of low voltage customers whereas larger size ground mounted transformers supply power to larger single or multiple distribution customers.

3.2 Asset Population

AusNet Services has a total of 61,382 distribution transformers [1] installed in the electricity distribution network A summary of the distribution transformer population by type is shown in figure 1.

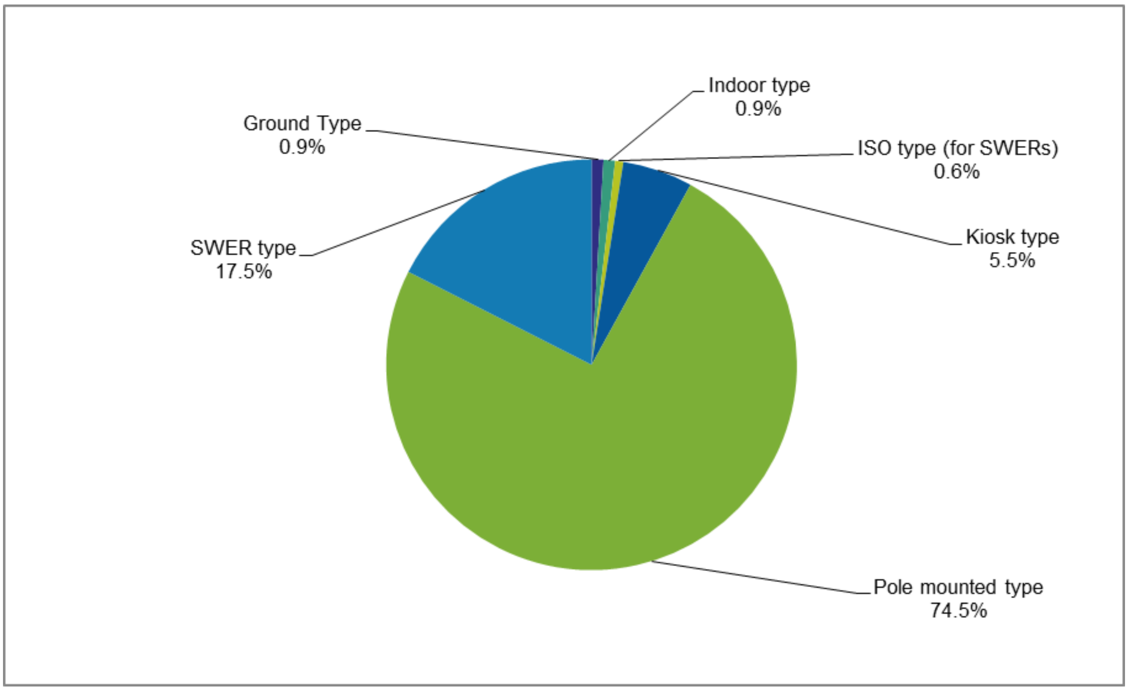

Figure 1 – Distribution Transformers by Type

Pole mounted distribution transformers represent approximately 93% of the total population of distribution transformers and they can be either three phase or single phase. ISO type and SWER type distribution transformers are pole mounted and they are single phase transformers generally used in rural distribution network in single earth wire return (SWER) medium voltage distribution systems. Kiosk, Ground and Indoor type distribution transformers are all ground mounted type.

1. RIN AusNet Services Electricity 2018 Category Analysis

3.3 Asset Age Profile

The average service age of all distribution transformer population is 28 years and the oldest being 80 years. Figure 2 shows the service age profile against distribution transformer type.

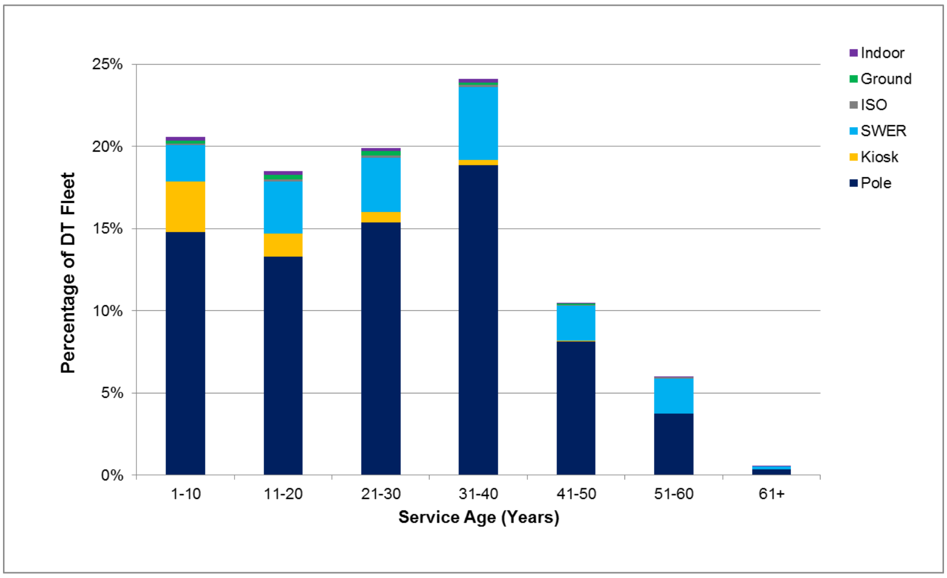

Figure 2 – Distribution Transformer Service Age by Transformer Type

Single Phase Transformers

Approximately 46.3% of the distribution transformer population are single phase type. The design of single-phase transformers has evolved over the last 50 years with reductions in losses, improvements in bushing porcelain, and a move in the 1990s from painted to galvanized tanks. AusNet Services' single-phase transformers were purchased to the prevailing Australian Standard and can be regarded as a homogenous population with a average service age of approximately 30 years, oldest being 80 years. Figure 3 shows the service age profile of single phase transformers.

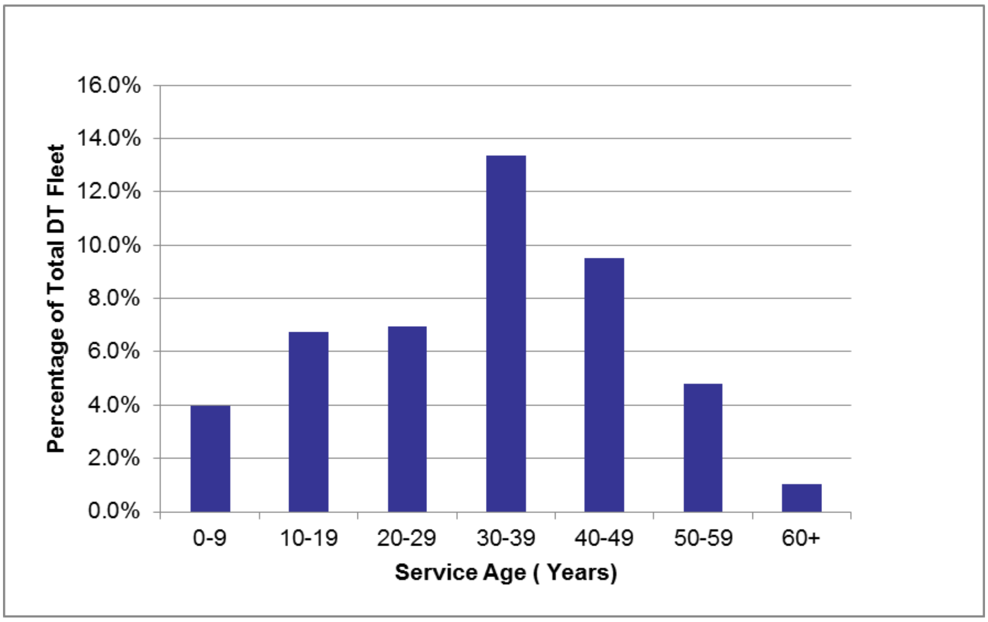

Figure 3 – Age Profile of Single Phase Transformers

Three Phase transformers

Approximately 34.9% of the distribution transformer population are three phase type. The rapid growth of underground residential estates to the south-east and north of Melbourne between has driven a steady increase in the number of three-phase Kiosk substations. The design of three-phase pole mounted transformers has also evolved over the last 50 years with reductions in losses, improvements in bushing porcelain, and a move from painted to galvanized tanks in more recent years. Three-phase transformers have been purchased to the prevailing Australian Standard and can be represented by a homogenous population with an average service age of approximately 23 years , oldest being 80 years. Figure 4 shows the service age profile of single phase transformers.

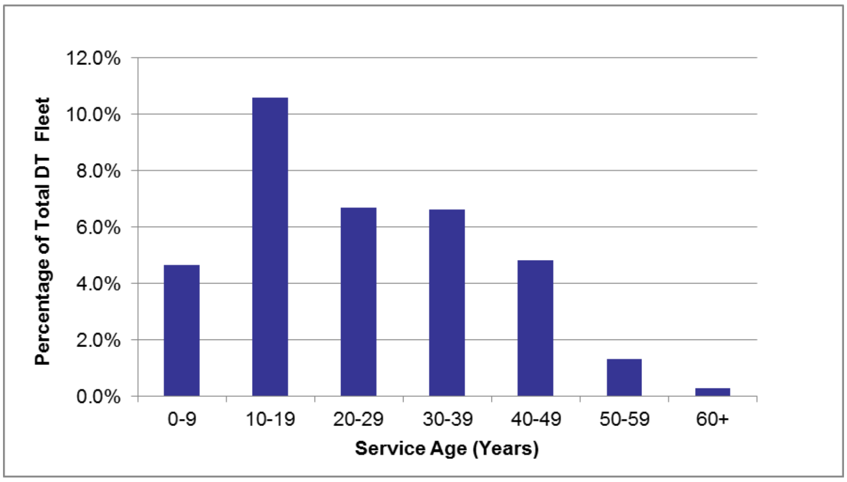

Figure 4-Age profile of Three Phase transformers

SWER Transformers

Approximately 18.7% distribution transformer population comprise of SWER transformers on the AusNet Services distribution network. The electrification of the rural areas of Victoria also drove the installation of SWER networks in the more remote areas of rural Victoria. The older SWER transformers have average service age of 32 years, oldest being 70 years. Figure 5 shows the service age profile of SWER type transformers.

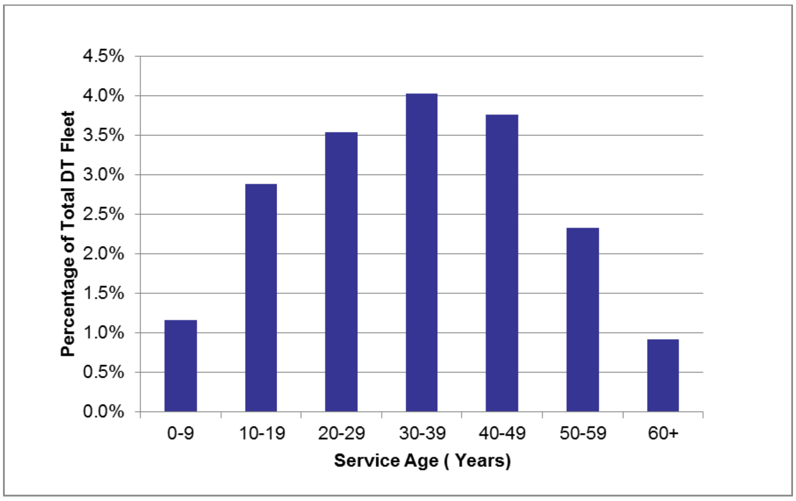

Figure 5-Age Profile of SWER Transformers

3.4 Asset Condition

A distribution transformer Health Score has been assessed for each distribution transformer in the electricity distribution network.

A common condition methodology has been developed which uses three criteria as condition indices:

1. Environmental deterioration
2. Power utilization factor (PUF %)
3. Number of low voltage circuit outages

Details on condition scoring methodology is given in Asset Health Report AHR -20-58.

The Table 1 provides a definition of the various condition scores and recommended action.

Condition Scoring Methodology			
Condition Score	**Condition Description**	**Summary of condition score**	**Remaining Life**
C1	Very Good	Transformer / Kiosk is relatively new. These units have been operating at utilisations less than 100%, with no reported outages associated with its LV circuits.	95%
C2	Good	Transformer has experienced one to two outages associated with its LV circuits. The galvanizing of the steel components of the transformer or Kiosk is starting to disappear.	70%
C3	Average	The Plant Utilisation Factor (PUF) has exceeded 100% and 3 to 4 incidents have been associated with its LV circuits. Some degree of oil leakage is identified but without any history of failure or major maintenance required. There are signs of early corrosion on the transformer's or Kiosk's steel components.	45%
C4	Poor	Transformer has experienced 5 to 6 LV outages associated with its LV circuits. Corrosion has become more prominent on the transformer or Kiosk; Unit has operated in excess of its rated capacity (refer to Table 2).	25%
C5	Very Poor	Transformer corrosion as the major issue leading towards replacement; Unit has operated well in excess of its rated capacity (refer to Table 2); Number of LV outages associated with its outgoing circuits has exceeded 7 events.	15%

Table 1- Condition Score definition and recommended action

Condition Score by Transformer Types

Condition profile of distribution transformer by type is shown in Figure 6.

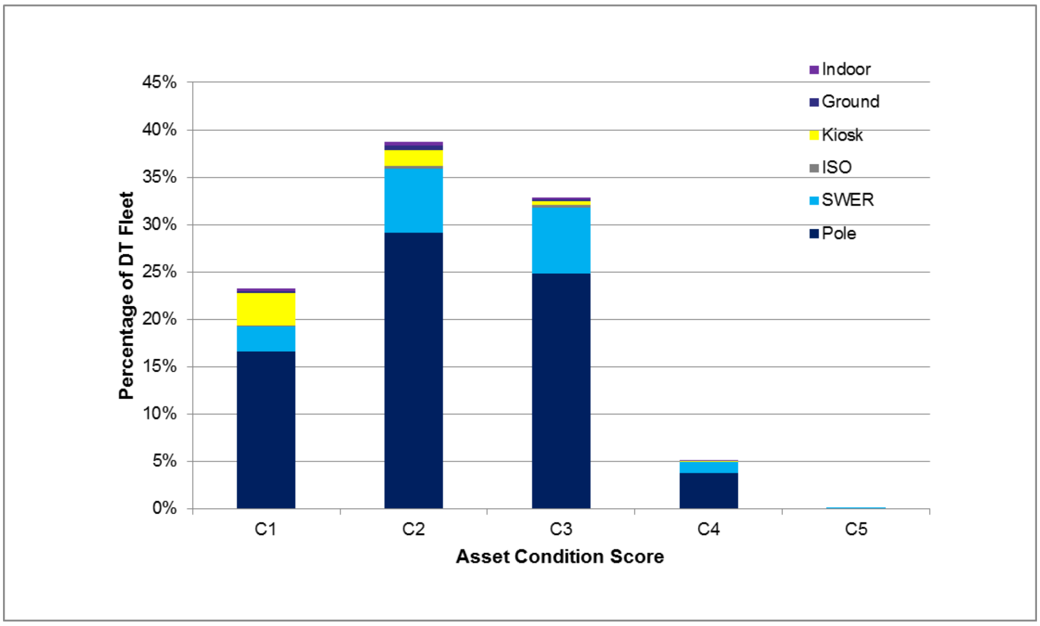

Figure 6 – Condition profile of Distribution Transformers by Type

Overall, the transformer fleet is in good condition, with 23% of its population in “Very Good” condition, over 39% in C2, 33% in C3, 5% in C4 and less than 1% in “Very Poor” condition (C5) which have been assessed as having 15 % remaining service potential.

Distribution transformer condition score by single phase, three phase and SWER type is shown in figure 7. The majority of single-phase transformers are in average or better condition with approximately 5% of the fleet in condition C4 and C5.

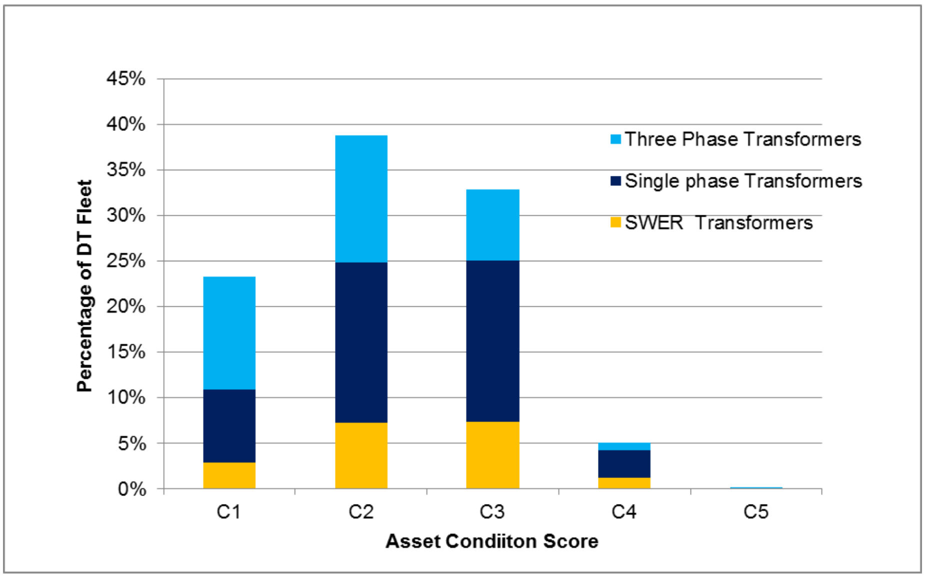

Figure 7 – Condition profile of Distribution Transformers by Single phase / Three Phase & SWER type

Typical "Very Poor" condition (C5) and "Poor" condition (C4) distribution transformers models are shown in Table 4 below. These are mainly very older models which have been in service more than 33 years and exposed to number of LV distribution faults during its service.

Transformer Type	Distribution Transformer Make of C4 & C5 Condition
Pole Single Phase	C.I.C
Pole Three Phase	
ISO /SWER	
Kiosk	
Ground	
Indoor	

Table 4 – Typical "Very Poor" condition (C5) & "Poor" condition (C4) Distribution Transformer Models

Transformer Power Utilisation (PUF)

The duration that a transformer is operated under high PUF ratios will determine the rate of deterioration of the electrical insulation of the transformer core and coils. With the roll out of Advanced Metering Infrastructure (AMI) meters in recent years, data is collected for each transformer every half an hour which can then produce the % PUF of that particular unit every 15 minutes. AMI metering method is more accurate than the traditional method of PUF calculation previously used based on customers' energy consumption billing data.

Average annual Transformer Power utilization factors (PUF) for single phase, three phase and SWER transformers in 2017 are shown in figure 8. Overall average utilization had been about 48%.
(Single phase - 41.8%, three phase -46.6%, SWER – 56.6%)

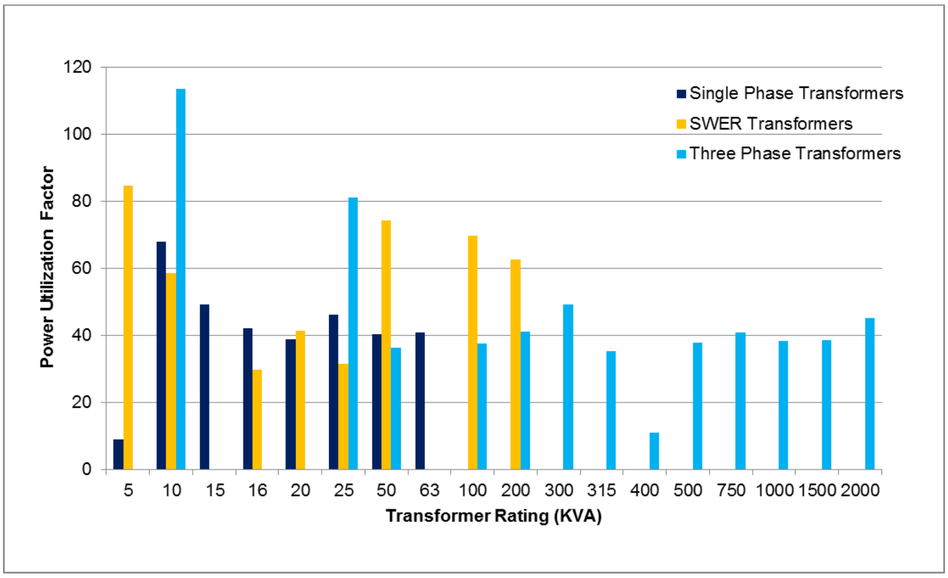

Figure 8 – Annual Average PUF of Distribution transformer types

3.5 Asset Criticality

Asset Criticality was determined by considering the following consequences of a distribution transformer failure with the failure effects mentioned below.

I. Bushfire Safety impact (community),
II. Community impact due to outages (unserved energy)
III. Health and Safety (Operators)

Asset criticality is the severity of consequence in a major failure of a distribution transformer at a certain location due to above failure effects irrespective of the likelihood of the actual failure. This gives an idea of transformer types located critical locations which represent the total value of risk $.

A bushfire Consequence model was developed combining the FLCM, weather data from CSIRO, assumptions on FFDI duration and VBRC findings to derive an expected consequence for a fire started at any time.

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Community impact due potential value of unserved energy is estimated based on the number of customers affected, value of customer reliability (VCR) and the mean time to restore (MTTR) power supply to customers.

The Figure 9 show the Relative asset criticality based on Distribution transformer types.

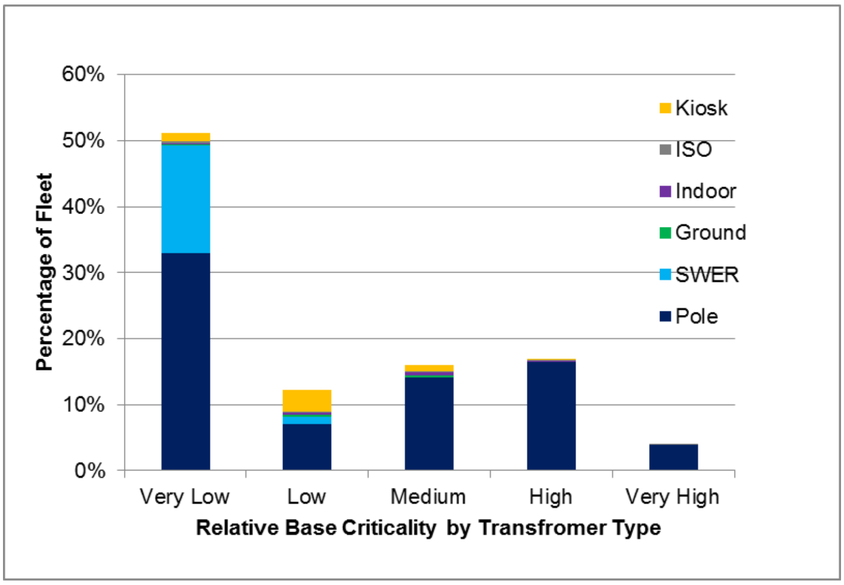

Figure 9 – Relative Base Criticality by Distribution transformer type

The applied interpretation of relative base criticality is shown in Table 5.

Criticality Bands	Definition
1	Total failure effect cost < 0.3 times Replacement Cost
2	Total Effect Cost is between 0.3 – 1.0 times of replacement cost
3	Total Effect Cost is between 1.0 - 3 times of replacement cost
4	Total Effect Cost is between 3 -10 times of replacement cost
5	Total Effect Cost exceeds 10 times of replacement cost

Table 5- Interpretation of Relative Base Criticality

Following observations are made on asset criticality:

- Approximately 3.9% and 16.8% of the total transformer population are of very high and high criticality respectively and they are mainly due to pole mounted distribution transformers. This is approximately of the pole mounted transformer population.(mainly non SWER substations)
- There are approximately 0.05 % of the total transformer population are very high criticality risk indoor type substations. This is approximately 5% of the indoor transformer population.
- There are approximately 0.22% of the transformer population are classified as high risk criticality of ground mounted transformer population (indoor, ground type and kiosks) This is approximately 10% of the ground type population ,16% of the indoor type population and 0.3% of the kiosk type transformer population.)
- There are approximately 0.1% of the total transformer population are high criticality SWER type transformers. This is approximately 0.4% the SWER transformer population.

3.6 Asset Performance

AusNet Services routinely analyses the root cause of unplanned work undertaken on distribution transformers and investigates all major failures, and tracks customer outages due to distribution transformer failures.

Planned Inspections

All pole mounted distribution transformers are subject to regular condition inspections in conjunction with line asset inspections. Kiosk, ground type and indoor substations are periodically inspected as part of the key switch inspection regime in accordance with the Asset Inspection Manual (30-4111).

Pole-mounted transformers are visually inspected together with their support structure every 37 months in the Hazardous Bushfire Risk Areas (HBRA) while pole-mounted transformers in non-HBRA regions are inspected every 61 months. Kiosks, ground type and indoor type transformers are visually inspected at intervals prescribed in the key switch inspection instruction together with the routine ground inspection and maintenance of the civil aspects of these sites. The civil aspects for ground-mounted installations include site surfacing, hazard signage, gates, fences and vegetation management.

AusNet Services is enhancing the inspection and monitoring process for large capacity installations supplying major loads to high profile commercial enterprises such as shopping centres. This occurs to ensure that flooding, fire or vegetation does not jeopardise supply reliability.

Installation earths are tested and maintained in accordance with AusNet Services' earth testing program. More detailed plant condition assessments such as operating temperatures, oil sampling/analysis, partial discharge and thermo-vision are being implemented on selected installations. This program is prioritised by customer criticality and plant utilisation.

Corrective Maintenance

Distribution transformers are essentially maintenance-free devices and relatively little maintenance is undertaken on site. Minor bushing damage, such as chips in the glazing of bushing sheds and small rust spots in paint work, can be restored on site. Such works are not part of scheduled maintenance programs but are a by-product of other maintenance activities such as inspection of the civil aspects of ground type substations, Kiosk and indoor substations or cross arm, pole or conductor replacements.

Maintenance activities such as replacement of bushings or bushing seals are undertaken in a workshop in conjunction with oil replacement and tank re-conditioning, as part of a refurbishment or overhaul program.

Refurbishment of larger capacity units is economic if the core and coil are in sound condition and there is a high probability of achieving decades of further service life considering its asset age and physical condition.

Work order Analysis in 2016 -2018 period show that approximately 53 % of the total pole mounted distribution transformer replacements were due to actual transformer failures and approximately 47% of the replacements were due to condition based asset replacements and transformer load monitoring results (PUF) . Total pole mounted transformer replacements is about 0.19% of the total pole mounted transformer fleet population. Details are shown in Table 6.

For the same period 2016-2018 approximately 38% of the total ground mounted type transformer failures (indoor, ground, kiosk) were due to actual transformer or switchgear failures and approximately 62% were due to condition based asset replacements. Total ground mounted transformer replacements is about 0.26% of the total ground mounted transformer fleet population.

DT Type	Transformer / Kiosk Replacements	2016	2017	2018
Pole mounted	Condition based Replacements	57	47	48
Pole mounted	Transformer Failures	78	54	44
Total (Pole mounted types)		135	101	92
Indoor /Ground /Kiosk	Condition based Replacements	7	3	9
Indoor /Ground /Kiosk	Transformer / Switchgear Failures	12	1	3
Total (Ground mounted types)		19	4	12
Grand Total		154	105	104

Table 6 – Distribution Transformer Replacements - 2016-2018

Approximately on the average 121 distribution transformers of all types had been replaced during the period 2016-2018 as proactive and reactive replacements. Although there is a decrease in the total number of distribution transformer replacements over the years, an increase of the ground mounted types is noted which is mainly due to proactive replacements. However it should be stated that the total number of transformer replacements is very much lower than derived from ‘simple sustainable’ ratio of asset fleet / mean asset life.

Hence it is important to further improve the present condition based inspection regime to identify proactive replacements, mainly kiosk types where switchgear defects had also been detected recently apart from transformer defects.

Major Asset Failures

There were two major failures reported in indoor kiosk type substations which require replacement of switchgear in 2018 as per Table 7 below.

Manufacturer	Model	Voltage (kV)	Size (KVA)	Year of Failure	Age at Failure	Substation Location	Major failure / Defect
C.I.C	RM6	22	300	August 2018	34	Leane Kirwan	HV Fuse candle failure and collateral damage.
	-	22	300	June 2018	25	Marina Godwin	Fire damage HV bushing / elbow connection failure

Table 7 - HV switchgear Replacement s -2018

4 Other Issues

4.1 PCB in Distribution Transformers

Older distribution transformers may have traces of PCB in oil. Polychlorinated Biphenyls (PCBs) in oil require special handling procedures to be followed during their life cycle management due to health and safety and environment concerns if contaminated with environment. Numbers of oil spills due to distribution transformers have reduced due to early replacements of leaking transformers reducing the environment damage due to oil leaks and possible PCB contamination.

4.2 HV Switchgear Issues in Kiosks /Indoor and Ground type Transformers

There are several older types HV and LV side switchgear associated with ground mounted distribution transformers developing issues and operation and maintenance of these switchgear is becoming difficult due to technical obsolence and no manufacturer support. Non availability of accurate technical data of the type switchgear associated with distribution transformers has been a hindrance for their life cycle planning.

5 Risk and Option Analysis

The drivers of this program are Bushfire safety risk, supply risks, health and safety risks to operators. Figure 10 and 11 provide an assessment of the risk based on the condition of the assets and the monetised consequence of failure.

Effect Cost / Replacement Cost Ratio	C1	C2	C3	C4	C5
>10	625	938	712	98	2
>3 <10	2376	3975	3262	537	4
>1 <3	1946	3442	2967	454	8
>0.25 <3	1160	2328	2002	323	5
<0.25	5805	11572	10796	1664	13

Figure 10 – Relative Base Criticality for Pole mounted transformers

Effect Cost / Replacement Cost Ratio	C1	C2	C3	C4	C5
>10	15	14	0	0	0
>3 <10	66	74	13	4	0
>1 <3	507	336	126	26	0
>0.25 <3	1347	881	271	19	0
<0.25	476	291	58	4	0

Figure 11 – Relative Base Criticality for Ground, indoor & Kiosk type transformers

Approximately 53% of the pole mounted transformers and 38% of all ground mounted transformers (including kiosks) during the period 2016-2018 were due to actual failures mainly due to random failures. Thus the total replacement is due to mixture reactive and proactive replacements. (refer section 3.6.2)

Hence replacement forecast of 125 distribution transformers (Pole top types: 120 per year, Ground types: 5 per year) for EDPR 2022-26 was estimated by considering the actual transformer replacements carried out in the period 2016-2018. Priority should be given to proactively replace transformers identified in ery high and high criticality locations with “Very Poor” condition (C5) and “Poor” condition (C4) as per risk matrices shown in Figures 10 and 11 above.

6 Asset Strategies

6.1 New Assets

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