Document No. UE PL 2044

December 2015

Asset High Risk of Failure Assessment

This document describes the purpose, calculation methodology and validation of a metric to assess assets at high risk of failure.

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Table of Contents

List of Tables

Table of Figures

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1. Executive Summary

1.1 Objective

United Energy is required by the National Electricity Rules to maintain the reliability, safety, quality, and security of the distribution network through the provision of prudent and efficient investment.

To comply with these requirements, the underlying health of the network must be understood as it is a key factor in forecasting and undertaking asset replacement. If the underlying network health is deteriorating, then an increasing number of assets will reach their end of life requiring increasing Repex to maintain reliability and network safety.

The Repex forecast developed by United Energy is a bottom up build using a number of detailed condition based and probabilistic approaches.

United Energy's objective is to develop an independent and robust model of the underlying health of the network, to be applied as a top down assessment of the total Repex needed to maintain reliability and network safety.

1.2 Options for Network Health Model

The key requirement for a model of network health is to provide a valid and reliable indicator of the need to take corrective action (primarily asset replacement) to maintain reliability and network safety. This key requirement is best met by a model which provides a measure of the number of assets that are at higher risk of failure (HROF), since assets replaced at end of life and upon failure are mainly those at higher risk of failure.

Several options for analysing the assets at HROF were considered and a preferred model was selected, as summarised in the table below.

	Option 1 - CBRM	Option 2 – Weibull Analysis	Option 3 – Assets passing an age threshold (preferred option)	Option 4 – Average Age	Option 5 – Residual Life
Gives meaningful measure of assets at risk of failure	✓	✓	✓	✗	✗
Data readily available for all assets	✗	✗	✓	✓	✓
Independent measure that can test replacement strategies	✗	✗	✓	✗	✗
Preferred Option	✗	✗	✓	✗	✗

Conditions Based Risk Management (CBRM) is a process to define the condition, performance and risk for a class of network assets. Weibull analysis is a process to obtain an accurate representation of assets that are at risk of failure due to age for an asset class. Both are well established methodologies broadly used across many industries upon which to base a model of assets at HROF. However, both are already used by United Energy for determining asset strategies and replacement needs for individual asset classes and thus are not an independent assessment for top down purposes. In addition, the data needed for these processes is extensive and not readily available for all asset classes.

The Average Age of assets in a network is relatively easy to calculate each year, by taking the age of all assets and calculating the average. Residual Life is an assessment based on the recovery revenue on an asset base. Fundamentally, neither of these models measure assets at HROF. Both suffer from the same critical limitations for use as an indicator of the underlying health of network assets. Firstly, the addition of new assets through network augmentations and new customer connections will bring down the network's average age and increase the residual service life without addressing any underlying asset condition deterioration. Secondly, for a particular level of recent asset replacement, the average age can be can be maintained or reduced (converse for residual life), whilst the number of assets at high risk of failure continue to increase. This is dependent on the age profile of the assets.

Assets Passing an Age Threshold was selected as the preferred option. This metric uses age as a proxy for condition and purely focuses on assets at the end of the life cycle that are entering the wear out phase, rather than the whole asset base. Weibull lives are used where available for an asset class, otherwise the economic life is used. The data used for the model is readily available in Regulatory Information Notice's (RIN's) provided to the AER.

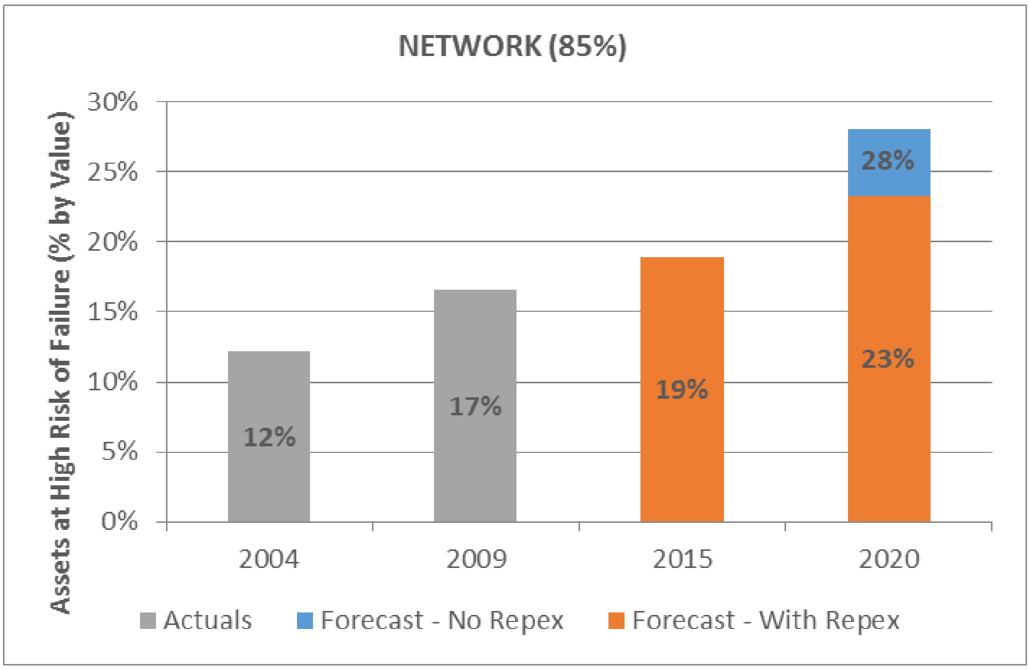
Analysis of the Weibull distribution identified that the inflection point of a nominal Weibull curve, where failures are predicted to rapidly increase, occurs where assets have reached 85% of their nominal life. It also corresponds to a CBRM health index threshold where risk of failure is said to be escalating. Therefore, the HROF threshold was selected to be 85% of useful life. Sensitivity analysis also shows that there is a linear relationship between the percentage threshold used and the volume or value of assets beyond the HROF threshold. As the metric is used for comparative purposes only (from year to year or for each regulatory period), the actual percentage selected will not have a material impact on the outcome. The sensitivity analysis concluded that 85% can be used as a reasonable measure of assets at high risk of failure based on asset age.

1.3 Results of HROF Modelling

United Energy has created a model that measures the assets at HROF for each asset class. This model presents the best case for assets at HROF as it assumes that all replacements made replace the oldest assets of that type. In practice, specific replacement strategies that are underway may replace younger assets for safety reasons, for example the replacement of HV ABC conductors to mitigate bushfire risk.

The results of the HROF modelling are shown at a network level in the chart below. This clearly shows that the assets reaching the HROF zone have increased over the last ten years and are forecast to increase in the next six years (from the start of 2015 to the end of 2020) despite forecast replacement expenditure. This indicates the underlying health of the network has been and will continue to deteriorate.

Total network forecast from the Assets in HROF model



The following table summarises the change in assets at HROF for the network between the start of 2015 and end of 2020. Without any replacements, the assets at HROF will increase from 19% to 28.1%, or around $800M. For our proposed Repex, which includes $408M of asset replacement for the 2016-20 period (including modelled and unmodelled asset classes and ZSS Primary Assets replacement), the proportion of assets replaced will still increase to 23.3%. Noting our equivalent asset replacement during the 2011-15 period was $375M, the forecast ongoing deterioration in network health strongly supports the need for an increase in asset replacement capex and overall Repex in the 2016-20 period to maintain reliability and network safety.

United Energy's overall strategy is to maintain reliability and network safety efficiently by complementing asset replacement with other strategies. This includes initiatives to improve asset inspection and condition monitoring to enable assets to be replaced as close as possible to their end of life (ideally just before imminent failure). It also includes initiatives focused on specific aspects of reliability and network safety, as outlined in our Network Reliability Assessment and Network Safety Assessment. In this way, reliability and network safety can be maintained efficiently whilst the underlying health of the network deteriorates, with a somewhat modest increase in both asset replacement capex and overall Repex in proportion to the overall increase in risk.

	Value of Assets ($M)	**% at HROF by Value**
Total Assets (2015)	$8741M	
Assets at HROF (2015)	$1654M	18.9%
New Assets reaching HROF 2015-2020	$803M	9.2%
Assets at HROF Forecast - No investment (2020)	$2457M	28.1%
HROF Assets replaced 2015-2020	$417M	4.8%
Assets at HROF Forecast - With investment (2020)	$2,040M	23.3%

The results of HROF modelling is presented for the eight AER modelled asset classes, and is included in Section 6 of this report. This provides insight into what asset classes are most influencing the results for the overall network. This assessment also provides a useful check for the level of proposed asset replacement, and the potential impact of an asset class on reliability and network safety.

1.4 Verification

Two verifications steps were taken to ensure correct functioning of the model and to ensure it was producing a robust output.

Firstly, checks were undertaken that the input data was taken from the appropriate RIN, and that it had been correctly translated into the model. Calculations in the model were then checked to ensure the model was functioning correctly and was free from errors. The model was found to be calculating the metrics as intended.

Secondly, the model output was assessed for sensitivity to inputs (asset life and unit rates) and key assumptions (age threshold). The sensitivity analysis found that the output trends identified were relatively insensitive to changes in asset lives and unit rates, and were largely independent to the threshold chosen to represent the start of the asset wear out phase.

1.5 Validation

In order to validate the Assets at HROF model, United Energy has tested the model against historical network performance. The network performance indicators included notifications (particularly priorities for asset replacement), replacement capex and replacement volumes, and outages and SAIFI. Validation has been performed on the overall network, and on an asset class basis.

Some comparisons are more relevant for some asset classes than for others. For example, SAIFI and outages are most relevant for asset classes where the strategy is to replace on failure. For asset classes where we replace on condition and seek to avoid failures, this indicator is less relevant. In fact, for ideal asset management, outages and SAIFI would remain constant (and zero) as Assets at HROF varies, and replacement volumes and capex would change in proportion.

The validation of the model is summarised in the following table.

Validation Summary Table

Validation Test	Poles	Overhead Conductor	Underground Cables	Dist. Switchgear	Dist. Transformer	ZSS Switchgear	ZSS Transformer	Services	OVERALL NETWORK	Comments
Notifications vs. Assets at HROF	(✓)	✓	✓	(✓)	(✓)	(✓)	(✓)	×	✓	
Replacement (Vol) vs. Assets at HROF	(✓)	(✓)	✓	(✓)	✓	(✓)	✓	×	✓	
Replacement ($) vs. Assets at HROF	(✓)	✓	×	✓	✓	(✓)	(✓)	×	✓	
High Priority Notifications vs. Replacement (Vol)	✓	(✓)	✓	(✓)	(✓)	(✓)	(✓)	×	(✓)	
SAIFI vs. Assets at HROF	N/A	✓	×	(✓)	N/A	N/A	N/A	N/A	✓	
Outages vs. Assets at HROF	N/A	✓	✓	✓	N/A	N/A	N/A	✓	×	

✓ Correlation of data
(✓) Correlation when knowledge of historical asset management / performance considered
× No Correlation of data but justified
N/A Insufficient data to allow correlation to be observed or not applicable to the asset class

The overall findings demonstrate the Assets at HROF model correlates strongly with key network performance indicators for the overall network, and broadly across most asset classes.

By inference, this strong correlation at the network level of Assets at HROF with key network performance metrics also demonstrates a poor correlation for model options 4 and 5, namely Average Age and Residual Life. This is because both Average Age and Residual Life are relatively constant over time, whilst the key network performance metrics have increased.

1.6 Conclusion

Assets at HROF is a robust model of the underlying health or condition of the network, and is therefore suitable for use in a top down assessment of the total Repex needed to maintain reliability and network safety.

The Asset at HROF model indicates that the underlying health of the network will continue to deteriorate, essentially due to aging assets, supporting the need for more Repex in the forthcoming period than in the current period to maintain reliability and network safety, all other factors being equal.

The Assets at HROF model can be relied upon as a robust indicator of network health since:

- It is soundly based on assets at the end of the life cycle that are entering the wear out phase.
- It is built on readily available data submitted to the AER and is therefore transparent.
- It has been verified by checking inputs and calculations for errors, and confirming it is not sensitive to variations in inputs like asset lives and unit rates, or the age threshold selected.
- It has been validated against historical network performance.

The model has been submitted to the AER with United Energy’s revised regulatory proposal.

2. Introduction

2.1 Background

United Energy is committed to the efficient and safe delivery of reliable services to customers. Efficient and effective management of United Energy's electricity network assets is critical to achieving this outcome. United Energy's asset management framework aims to:

- Ensure the prudent, efficient and reliable delivery of electricity that meets customers' and stakeholder' needs;
- Ensure the safety of the public and United Energy's personnel and contractors at all times;
- Ensure that all compliance obligations are met; and
- Manage risk efficiently.

United Energy's network strategy aims to manage the level of risk present from its entire population of network assets through an efficient combination of expenditure to address asset replacement and augmentation, reliability and network safety strategies and other initiatives.

United Energy has an aging asset population, with much of the electricity distribution network being established in the 1960's and 70's. It is of concern that many of these assets are now approaching their expected/design life and are in the 'wear out' phase of their lifecycle. The wear out phase typically results in an increasing number of defects and maintenance notifications. The longer term impact is expected to be a need for a higher level of expenditure to maintain assets, replace assets or undertake alternate strategies to maintain network reliability and safety.

2.2 Document purpose

The objective of this assessment is to develop a model of the underlying health of network assets, in order to inform our forecast of Repex needed to maintain reliability and network safety.

The purpose of this report is to:

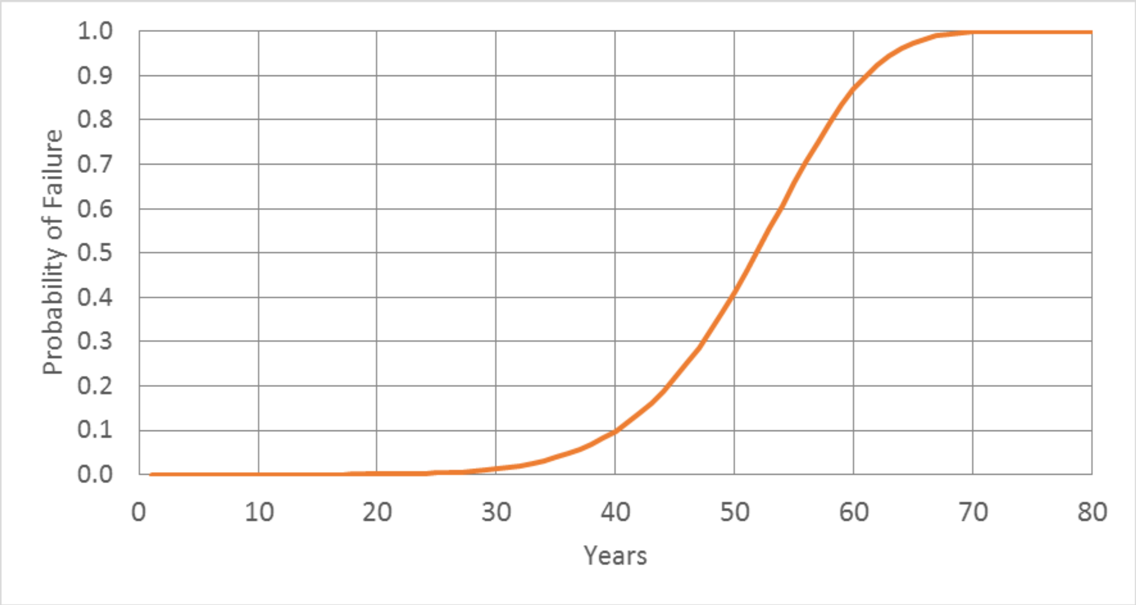
- Set out the reasons for evaluating the number of assets at high risk of failure due to asset age
- Provide background on the options considered to measure these high risk aging assets and the chosen approach (the '**High Risk of Failure**' metric or HROF)
- Provide high level details on the modelling that has been conducted, including assumptions made
- Present the outcome of the modelling and discuss the forecast for HROF assets
- Provide validation of the HROF model through analysis of historical network performance metrics.

3. Why measure assets at high risk of failure?

3.1 Probability of failure with asset age

The relationship between asset age and the probability of asset failure is well known. Assets typically have a long period of serviceable life with negligible failures, followed by a period of deterioration or the 'wear out phase' which leads to increasing failure. This is reflected by the Weibull probability density function, which can be used to depict the distribution of failure rates for a particular asset class. Figure 1 shows a typical Weibull probability density function for an asset with an effective life of 55 years.

Figure 1: Typical Weibull distribution for as asset with 55 years of expected life



With much of the United Energy network being established in the 1960's and 70's and with a typical 50-60 asset life expectancy, many assets are getting close to the end of their effective life. This increasing age of assets ultimately results in an increased risk of asset failure and the potential to impact on network reliability and safety. It is therefore considered important for United Energy to understand this trend and ensure that they can respond by adopting the most prudent and efficient approach to asset management, to ensure safety and reliability is not compromised, while minimising increases in forecast Repex.

3.2 Requirement for risk measure

United Energy has determined the need for a metric to measure the risk of asset failure due to the asset age. The metric is referred to the High Risk of Failure (HROF) metric. The purpose of this metric is to:

- Allow a direct comparison of the number of assets at HROF between each year and regulatory period to assess changing risk to the network.
- To test that replacement strategies in place are prudent and efficient, drawing a balance between actual replacements and supporting strategies to maintain reliability and safety. Such tests include the ability to:
  (a) Demonstrate if replacement expenditure is sufficient to sustain the assets at HROF
  (b) Determine the level of expenditure that would be required to maintain same level of assets at HROF
  (c) Evaluate where replacement expenditure is not reducing assets at HROF and whether strategies are prudent and efficient.

(d) Allow the ‘rolling up’ of asset class assessments to form a metric for the entire network that can be used as an indicator of the ‘underlying state’ of the network in a ‘top down’ assessment of forecast Repex.

It should be noted that the metric is not intended to be used directly to determine replacement forecasts as an asset class level. United Energy have an established approach to forecasting, which takes into account the Weibull model for the asset based on actual replacements undertaken, the asset condition, failure trends and any specific projects that are underway.

The metric will need to:

- Give a meaningful measure of assets that are at high risk of failure
- Be able to be consistently calculated each year or regulatory period
- Make use of data that is readily available for all assets
- Be independent from the analysis used in asset strategies to forecast replacements

The HROF metric is utilised by reliability and safety models to evaluate the reliability and safety risk arising from the aging asset base risks. Further details of how these risks are evaluated can be found in the Network Reliability Assessment (UE PL 2304) (1) and Network Safety Assessment document (UE PL 2043) (2).

4. Options for measuring risk of asset failure

The options that were considered for this measure are:

1. Condition based risk management
2. Full Weibull analysis of assets at risk of failure
3. Assets passing an age threshold
4. Average asset life
5. Residual life

These options are discussed in the following sections.

4.1 Option1: Condition Based Risk Management (CBRM)

Condition Based Risk Management (CBRM) is a structured process that combines asset information, engineering knowledge and practical experience to define future condition, performance and risk for network assets. The methodology has been progressively developed over a number of years and has been successfully applied many times, helping electricity network companies around the world to deliver effective asset related risk management. CBRM has been widely accepted by AER and OFGEM as a sound model to demonstrate a risk approach to asset management decisions.

CBRM estimates risk based on a number of factors applied to specific assets. The drivers for this assessment are age, operational conditions and environmental conditions. These are applied by first generating HI1 (Health Index 1) which is solely based on age, this index is then modified by the other factors previously mentioned in order to provide an asset specific HI (HI2) and then quantify risk. Typically, deviation between HI1 and HI2 is minor, therefore it is reasonable to define age as the most important measure. This correlates with the internal Weibull model which we use, which also defines a level of risk based on the age of an asset.

This measure of risk of failure is the most accurate approach that could be taken for forecasting the assets at HROF. However, United Energy only has CBRM in place for four different assets – poles, cross arms, Zone Substation (ZSS) transformers and circuit breakers – and so would not be able to use CBRM as a consistent approach to forecasting HROF across all assets. The implementation of this model across all asset classes is a high cost activity and a longer term plan will be required to adopt these models for all assets. In addition, a large amount of data will need to be captured and refined in order to implement these models.

4.2 Option 2: Full Weibull analysis of assets at risk of failure

Carrying out a full Weibull analysis on each asset class and subcategory of asset would allow United Energy to obtain an accurate representation of assets that are at risk of failure due to age. This analysis, would use failure data to create a Weibull curve for each asset subcategory and then determine a suitable band / threshold for classing assets at risk of failure.

There are several reasons why this approach is not the preferred option at this stage:

- Sufficient data is not available to create meaningful Weibull curves for all asset sub-categories.
- As the replacement forecast method used already uses the Weibull data that is available and meaningful, this method would not provide an independent assessment that would allow the replacement strategy to be tested.
- Creating a model that considers Weibull analysis on each individual asset would be complex and would require significant resources to complete. It is considered somewhat excessive for the measure of assets at risk of failure.

4.3 Option 3: Assets passing an age threshold

This option sets a fixed point in an assets life where it is considered to be approaching the wear out phase or is at 'High Risk of Failure'. The option considered uses a percentage of the asset Useful Life (85%, 90%, 100% etc.). This effectively provides a metric that is purely focused on the assets that are at the tail end of the asset age profiles and therefore at high risk of failure. It filters out new assets and assets that are within the low failure risk range which can ultimately cloud the assessment.

Using an age threshold has other benefits:

- Provides an independent metric that allows a top down assessment of assets at HROF that can be used to test replacement strategies
- Can easily be applied to the Useful Life of all assets
- Can be relatively easily calculated from information provided to the AER for RINs, not requiring complex modelling
- Percentage threshold can be set to align with CBRM risk approach

4.4 Option 4: Average Age

The average age of assets in the network is a relatively easy value to measure and track as the asset age profile changes. However, this option does not focus on the assets that are reaching the end of their Useful Life, where the risk of failure becomes higher and therefore isn't considered a good indication of the risk of failure of the assets due to age. This is demonstrated by the following example:

Table 1 reflects the asset age profiles for poles, with the first graph depicting the current age profile and the second graph the forecast age profile in 15 years' time. The forecast profile shows a high number of assets with a low asset age due to replacements made to aging assets, this includes replacement of staked poles which have a Useful Life of 25 years.

Table 1: Average Life vs last 15% of Useful Life

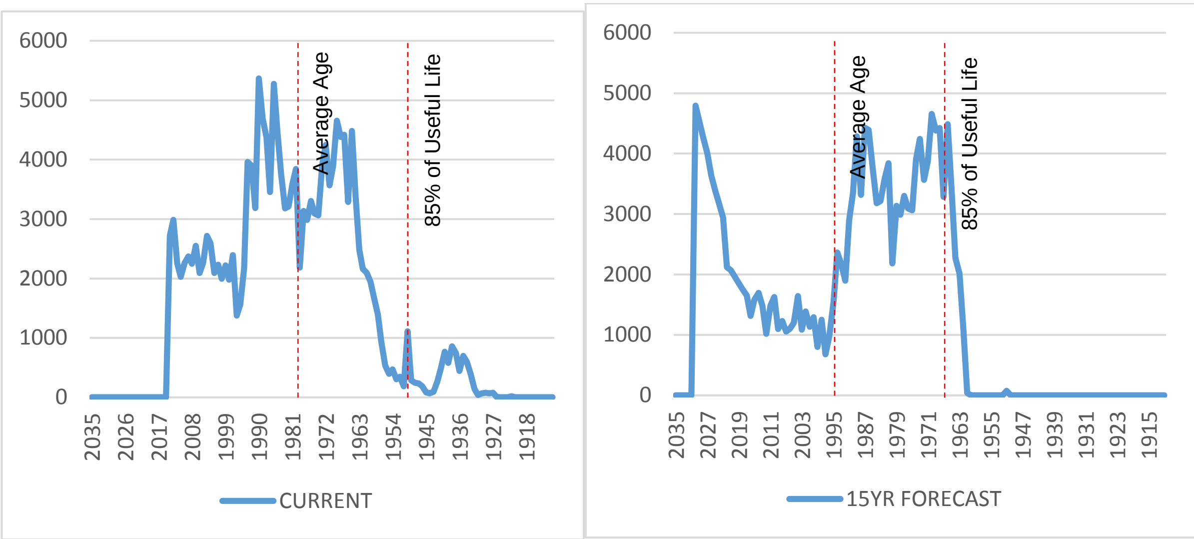
Weighted Average Age – 2015 (yrs)	Volume Weighted Average Age (yrs)	Change in Weighted Average Age (%)	Assets in last 15% of Useful Life (%)	Change in assets in last 15% of Useful Life (%)[1]
2015	35		7%	
2030	41	17%	28%	21%

As shown in Table 1, in the 15 years the assets at the tail end of the asset age profile (taken as in the last 15% of their Useful Life) increases by 21% due to significant step increase in the number of poles installed from 1960 onwards. The average life of the pole assets (weighted by volume for each sub-category) only increases from 35 to 41 years, so an increase of 17%. The average age is effectively reduced by the installation of the new assets.

The average life does not adequately reflect the number of assets that are at high risk of failure as essentially those assets are balanced out or reduced in the average age by the new replacements. In some assets, the average life may appear to be staying constant or even getting younger, although the number of assets at the end of their life is still increasing.

[1] Assets in last 15% of Useful Life is based on value in this table

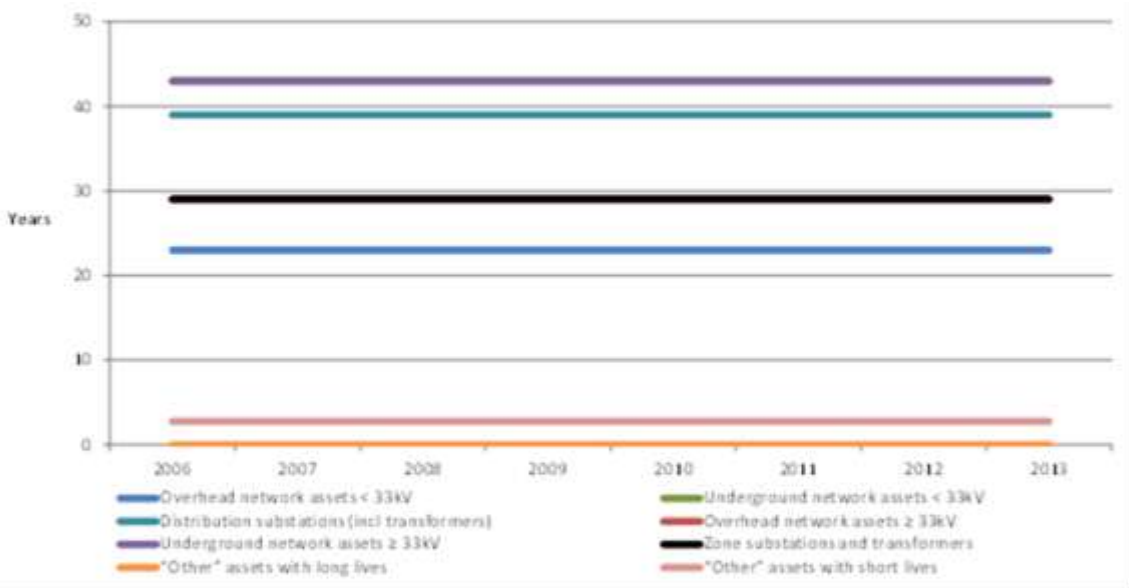
Figure 2: Age Profile of Pole Assets – 2015 and 2030[2]



4.5 Option 5: Residual Life

Another measure of the life of the assets is the Residual Life which is provided to the AER in Table 3.3.4.2 of the annual economic benchmarking RIN. The AER used the data provided by United Energy to produce the chart shown in Figure 3 which shows a flat age profile for each asset. However, this residual life value is based on the recovery revenue on an asset base.

Figure 3: United Energy estimated residual service life network assets



Source: AER, Preliminary Decision United Energy Distribution determination 2016 to 2020, Attachment 6 – Capital Expenditure, page 84

[2] 85% of Useful Life threshold shown on the graph is indicative only as in reality a different threshold is used for each subcategory.

The AER has used this residual life in their assessment of United Energy's Repex requirements, concluding that:

- the network assets are staying the same age
- the health of United Energy's asset base has been maintained
- the historical level of capex has not resulted in a deterioration of residual asset lives

The key driver for asset replacement is the volume of assets approaching their end of life. This information cannot be obtained from the average residual life metric, in a similar way to limitations of using the average asset age (refer section 4.4). With a large volume of replacements installed, the average age of the asset can be reduced or maintained, whereas the number of assets approaching the end of their life and therefor at high risk of failure may still be increasing.

In fact, the AER recognises the limitations of its residual life analysis, as noted below[3]:

> *"We acknowledge limitations exist when using estimated residual service life to indicate the trend in the underlying condition of network assets. Large volumes of network augmentation and connections can result in a large stock of new assets being installed in the network, which may bring down the network's average age. In this way, the residual service life of the assets may increase without necessarily addressing any underlying asset condition deterioration."*

Despite this acknowledgment, however, the AER concluded that[4]:

> *"The flat trend in residual lives (where age is a proxy for asset condition) suggests that the health of United Energy's asset base has been maintained."*

We cannot accept the AER's conclusion. As already explained, this conclusion cannot be drawn from the residual life metric.

4.6 Recommended Option: Assets passing age threshold

Using an age threshold based on a percentage of the Useful Life was selected as the preferred option. The basis for this recommendation is summarised in Table 2. Section 4.7 details the percentage threshold chosen for this option, together with the basis and validation of the threshold.

Table 2: Options analysis for HROF metric

	Option 1 - CBRM	Option 2 – Weibull Analysis	Option 3 – Assets passing an age threshold	Option 4 – Average age	Option 5 – Residual Life
Gives meaningful measure of assets at risk of failure	✓	✓	✓	✗	✗
Data readily available for all assets	✗	✗	✓	✓	✓
Independent measure that can test replacement strategies	✓	✗	✓	✗	✗
Preferred Option	✗	✗	✓	✗	✗

3 AER, Preliminary Decision, Attachment 6, page 6-149.
4 Ibid, page 6-84.

4.7 Validation of the percentage threshold of the recommended option

Analysis of the Weibull distribution identified that the inflection point of a nominal Weibull curve, where failures are predicted to rapidly increase, occurs where assets have reached 85% of their nominal life. It also corresponds to a CBRM health index threshold where risk of failure is said to be escalating. Therefore, the HROF threshold was selected to be 85% of useful life.

For the purpose of this report, when the age of an asset reaches or exceeds 85% of its Useful Life, it is classed at being at '**High Risk of Failure' (HROF)**. This threshold was selected for two reasons:

(a) It corresponds to the age at which the rate of failures is predicted to rapidly increase based on a nominal Weibull Curve with an effective life of 55 years. This nominal curve reaches maximum acceleration of failures at 47 years, equivalent to 85% of the effective life of 55 years.

(b) It corresponds to a CBRM health index threshold where risk of failure is said to be escalating. This is discussed in section 4.7.1.

The selection of this 85% threshold was then validated through sensitivity analysis. This analysis used alternative percentage thresholds to check the difference in HROF results obtained and is summarised in section 4.7.2. This determined that there is a linear relationship between assets at HROF and the percentage of Useful Life threshold used. As this metric is to be used as a comparative metric, showing change in assets at HROF from year to year, the percentage selected will therefore not have a material impact on the outcome.

The validation tests carried out concluded that the 85% of Useful Life threshold can be used as a reasonable measure of assets at high risk of failure due to asset age.

4.7.1. Alignment with CBRM

The CBRM methodology centres on the principle of checkpoints changing an asset from green (low risk), yellow (escalating risk) to red (highest risk). These are defined as Health Index (HI) bounds of 0-4 for green, 4-7 for yellow ('End of Life' at 5.5), and 7+ for red. For more detail on the CBRM methodology refer to 'Application of CBRM with United Energy Report (EA Technology report no. J000158-1)' (3).

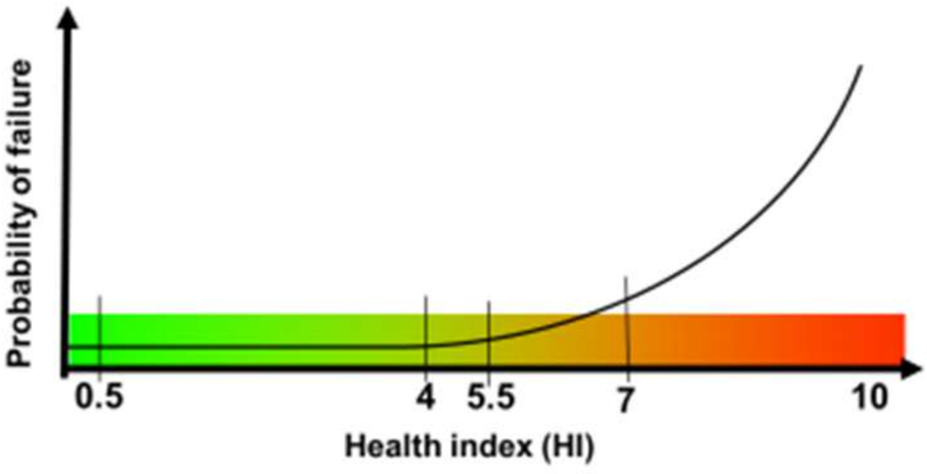


Figure 2-3 Relationship between Health Index and Probability of Failure

Source: CBRM Report for UE

HI is calculated using the formula below:

$$HI_{t_1} = HI_{t_0} \cdot \exp\left\{\frac{B \cdot (t_1 - t_0)}{age_f}\right\}$$

where:

HI_{t_1} = health index at time t_1

B = ageing constant

age_f = ageing rate reduction factor

$(t_1 - t_2)$ = average expected life

Source: CBRM Report for UE (Equ 2.2)

Table 3 shows how the CBRM risk profile aligns with the standard Weibull Distribution curve. 85% of Useful Life aligns with CBRM HI level 4, where the risk is escalating.

Table 3: Correlation between CBRM and Standard Weibull Curve

Risk Stage	CBRM HI1	% of Useful Life based on Std Weibull Curve	Weibull Characteristic
Escalating Risk	4	85%	Maximum acceleration of failure rate
CBRM defined 'End of Life'	5.5	100%	Peak failure density (most failures expected)
Highest Risk	7	108%	>80% chance of failure

In order to demonstrate the alignment of the CBRM model outcomes with this approach a comparison table has developed to identify the number of volumes at each risk stage for the following for the asset classes:

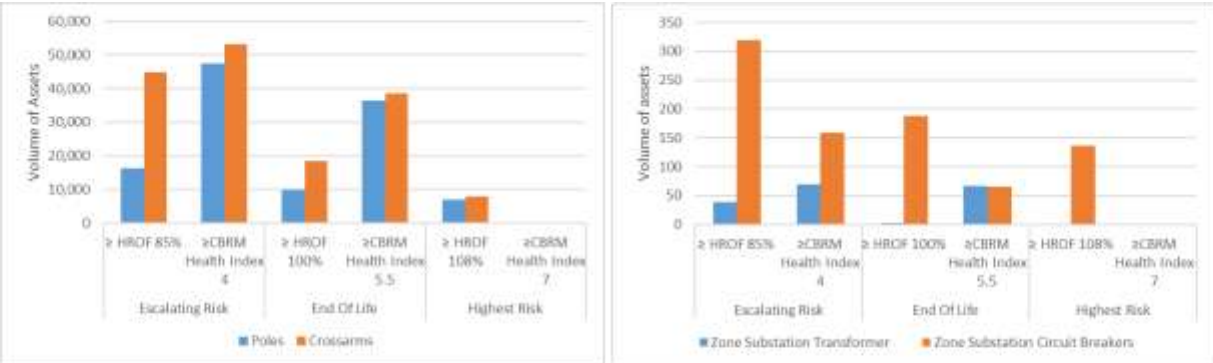
- Zone substation Transformers
- Zone Substation Circuit Breakers
- Poles
- Crossarms

Table 4 counts the number of assets within the risk window to compare the CBRM and HROF models for the equivalent risk stages defined in Table 3.

Table 4: Correlation between CBRM and HROF metric

	Escalating Risk		End Of Life		Highest Risk	
	≥ HROF 85%	≥CBRM Health Index 4	≥ HROF 100%	≥CBRM Health Index 5.5	≥ HROF 108%	≥CBRM Health Index 7
ZSS TX	38	69	2	67	1	0
ZSS CB[5]	320	159	188	65	136	0
Poles	16,252	47,520	9,831	36,434	6,969	299
Crossarms	44,804	53,162	18,430	38,474	7,926	0

Figure 4: Correlation between CBRM and HROF metric



The key differences between the two models are demonstrated in the chart above. In general, the CBRM index identifies higher volume for the escalating risk and end of life categories. Therefore, it can be concluded that the HROF method will generally identify fewer asset at risk than CBRM. This is expected as CBRM takes further details in addition to the asset age to determine its health index profile.

It can be concluded that in order to align the risk profiles of the two models the selection of a threshold at 85% will provide a good limit to align the health index and useful life as both models identify this as where the rate of change of deterioration is at the highest level.

4.7.2. Sensitivity Analysis

In order to identify a valid level for the percentage of Useful Life to be used analysis has been run on the current asset age profile for a range of Useful Life thresholds ranging from 50% to 120%. This has been carried out at a network level.

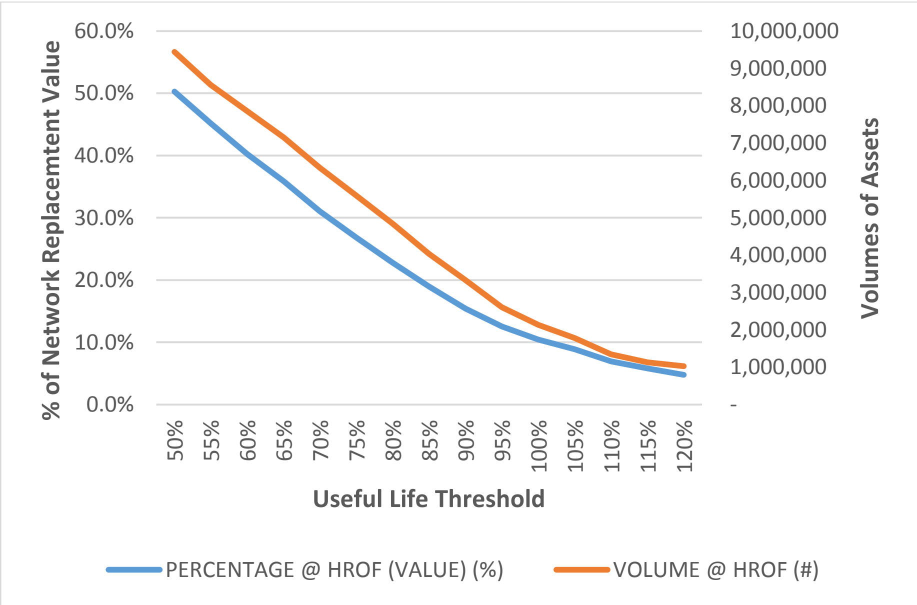
The table below summarises the results of HROF modelling at a network level for different thresholds and can be used to assess the impact it has to the volumes of assets and the percentage of replacement value that are exceeding these limits.

[5] Zone substation isolators have been removed from the HROF model figures quoted in table to align with CBRM models

Table 5: Useful Life Threshold vs Assets at HROF - Network

Useful Life Threshold	PERCENTAGE @ HROF (VALUE) (%)	VOLUME @ HROF (#)
50%	50%	9,440,747
55%	45%	8,557,241
60%	40%	7,853,423
65%	36%	7,152,828
70%	31%	6,343,693
75%	27%	5,593,362
80%	23%	4,843,286
85%	19%	4,038,001
90%	15%	3,328,641
95%	13%	2,603,902
100%	10%	2,131,989
105%	9%	1,783,610
110%	7%	1,341,565
115%	6%	1,132,806
120%	5%	1,030,860

Figure 5: Useful Life Threshold vs Assets at HROF - Network



The table and chart above demonstrates that the network level impact is a linear relationship for both volume of assets and percentage of replacement value. Therefore, it can be concluded that setting the limit at any level across the useful life threshold will not have a material impact to the outcome, given that the purpose of the metric is to allow a comparison to assets at HROF from year to year, or for each regulatory period.

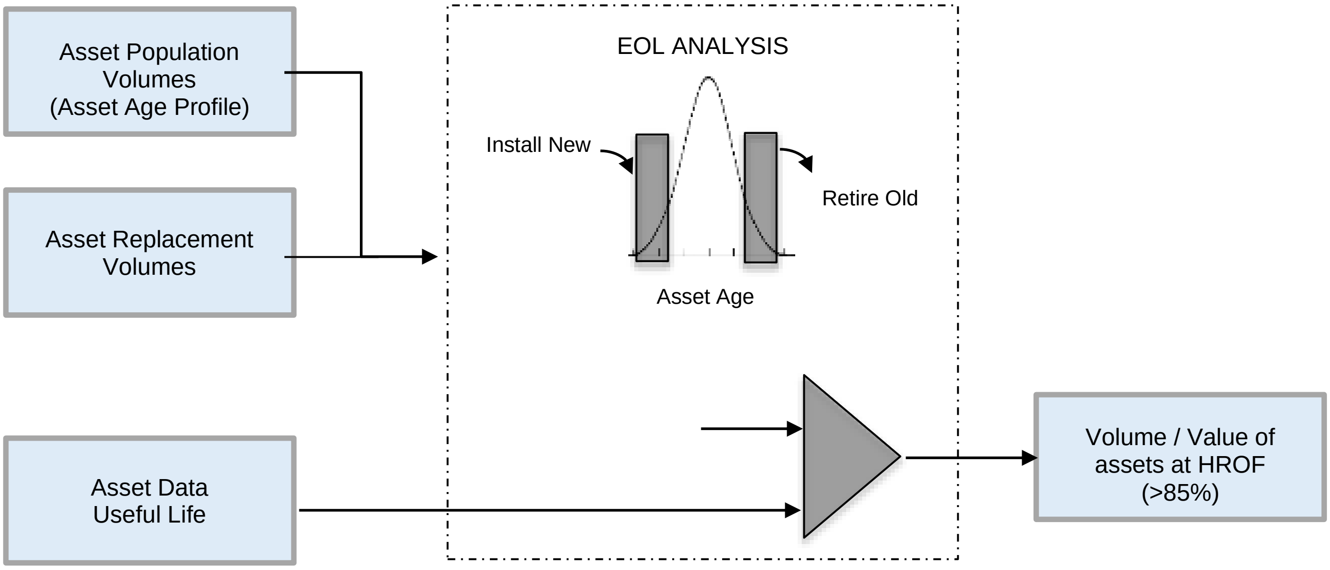
5. Methodology for assessing assets at high risk of failure

The HROF model combined information from a number of sources that have been used to build UEs forecast Repex and reliability expenditure requirements to assess the number of assets in the wear out phase of their lifecycle.

5.1 High Risk of Failure Model Overview

United Energy has developed an in-house model to determine the volume and percentage of assets at HROF. The model takes the inputs of asset age profile, forecast replacement volumes and asset data Useful Life and calculates the volumes and percentages of assets at HROF. It can be used for historical, current or forecast data.

Figure 6: Flow chart for High Risk of Failure Model



5.2 Model methodology / assumptions

The HROF needed several key assumptions and required information about the asset characteristics. To ensure accuracy and consistency, the information was sourced from key models and information sheets used by UE to build its Regulatory submission. The data requirements and the sources are described in the following sections.

5.2.1. Asset Class Grouping

The Asset Classes align with those assigned in the RIN tab ‘2.2 Repex’ age profile template from 2015.

The analysis in the HROF Model has focused on the Asset Category level (for example, the Poles Asset Class includes wood, concrete and steel poles as well as poles that have been staked) . Any assets that are not included in the RIN template have not been assigned an age profile and therefore don’t form part of the HROF assessment. These are typically fairly minor assets and are not considered to have a significant impact on analysis.

The assets that are included in each class are provided in Appendix A.

5.2.2. Asset age profiles

The model uses the asset age profiles that were provided to the AER in tab '5.2 Asset Age Profile' in the document 'United Energy Category Analysis RIN – Consolidated – FINAL' that was submitted as part of the EDPR for 2015-20. These age profiles were audited by an independent auditor and the methodology for developing the age profiles is documented. The age profiles represent United Energy's network at the start of 2015.

5.2.3. Forecast replacements

The model uses the replacement volumes that were provided to the AER in tab '2.2 Repex' in the document 'United Energy – EDPR Capex forecast sent to the AER – April 2015' that was submitted as part of the EDPR for 2015-20.

For each of the forecast years, the model removes the equivalent number of assets from the end of the asset age profile. This means that it is representing the best case in regards to how much the assets at HROF will be impacted by forecast replacements as it assumes that all replacements are made to assets at the end of the Age Profile. However, in practice, some replacements will be made to assets that are not at HROF, for example due to type replacements for safety drivers or external drivers such as storms or third party damage.

5.2.4. Useful Life and End of Life Threshold

The Useful Life is taken as the Weibull Life calculated from actual asset replacements / failures where there is sufficient data available. Where sufficient data is not available, the Economic Life provided to the AER as part of the RIN Reporting (tab 5.2 Asset Age Profile) is used. A list of the Useful Lives used in the model is provided in Appendix B.

The Useful Life is assigned to each subcategory within the asset class. The HROF threshold is then calculated as 85% of this value. For example, wooden poles have a Useful Life of 70 years, giving an HROF threshold of 59.5 years. The volume of assets that exceed this threshold is then determined based on the age profile for each subcategory.

5.2.5. Assets unit rates

The model converts the volume of assets at HROF into the value of assets at HROF ($m). The unit rate of each asset used for this conversion has been derived from:

- The effective unit rate (applied at the sub category level) that was used in developing the forecast Repex. This was calculated as the total forecast expenditure divided by the total replacement volumes for the period 2015 to 2020 that were submitted as part of the EDPR.
- HV bare overhead conductors were considered as one asset subcategory when calculating the unit rate to account for the methodology required to split the volumes into the categories required by the AER.
- The model accounts for where assets are replaced with alternative types of assets by applying the unit rate for the asset being installed.
- Where no assets were forecast for replacement the TOC was applied.

5.2.6. Percentage of Assets at End of Life

The percentage of assets at End of Life is determined in two ways a) based on volumes and b) based on value.

Volume based: The percentage by volume are purely based on the number of assets that exceed the End of Life threshold as a proportion of the total volume of assets in that category. This has been calculated at a subcategory, asset class and whole of network level. This method can easily be related to the Asset Age Profile. However, it can result in distortion of the summarised data at an asset class or whole network level. Such distortion occurs when there are a high number of assets with a low value, which elevates the % of assets at End of Life. Similarly, if there are a lower number of assets at End of Life that have a high asset value then these will be somewhat watered down in the volume assessment.

Value based: The percentage by value takes into account the value of each asset by subcategory by assigning the unit rate. The total value of assets that exceed the End of Life threshold is then calculated and compared to the total value of the assets in that subcategory.

On a subcategory level, the value based percentages and volume based percentages are the same. When summed for asset class or whole of network, this approach results in a different percentage of assets at End of Life due to the variation in values across the subcategories. This however, gives a more realistic picture of the assets at the End of Life as it reflects the cost of replacement of these older assets.

5.3 Verification of the Model

5.3.1. Quality checks

United Energy has undertaken a number of checks to verify the quality of data the model is using and also to verify that the model is performing the calculation as it should.

The following checks on the inputs have been undertaken:

1. Age profiles volumes match AER category Analysis RIN
2. Age profiles volumes match previous EDPR models
3. Unit rates are aligned with Determination RIN
4. REPEX forecast is aligned with model
5. Checked asset lives against Weibull models and economic lives.

The following checks on the model have been undertaken:

1. Checked formulas with in the sheet are undertaking all calculations as expected
2. Created a test assets class and worked through the model to test output.

5.3.2. Variable Sensitivity

A scenario analysis was undertaken on a number of variables to assess the robustness of the model and sensitivities of the output to changing the key input assumptions. Six scenarios were created using different combinations of historic and forecast asset lives and unit rates. Table 6 summarises the inputs and outputs of each of the six scenarios.

Table 6: High Risk of Failure Model Verification Scenarios

	Inputs			Outputs	
Scenarios	**Asset life**	**Useful Life %**	**Unit Rates**		
Scenario 1	Weibull Expected Lives	70%	2015 EDPR Rates (TOC)	% HROF by Value	% HROF by Volume
Scenario 2 (expected scenario)	Weibull Expected Lives	85%	2015 EDPR Rates (TOC)	% HROF by Value	% HROF by Volume
Scenario 3	Weibull Expected Lives	105%	2015 EDPR Rates (TOC)	% HROF by Value	% HROF by Volume
Scenario 4	Weibull Expected Lives	85%	Target Rates at 2009	% HROF by Value	% HROF by Volume
Scenario 5	Expected Lives used in 2009 EDPR	85%	2015 EDPR Rates (TOC)	% HROF by Value	% HROF by Volume
Scenario 6	Expected Lives used in 2004 EDPR	85%	2015 EDPR Rates (TOC)	% HROF by Value	% HROF by Volume

For a full list of the scenarios refer to Appendix C.

Table 7 summarises the outcome of the scenario analysis. The crosses (plus signs) indicate where the scenario shows an increasing trend in the value of assets at HROF from 2015 to 2020. The dashes (minus signs) indicate where the scenario shows a decreasing trend in the value of assets at HROF from 2015 to 2020.

Scenarios 2, 4, 5 and 6 all use a threshold of 85% and vary the input unit rates and expected lives. In 95% of cases the same trend was maintained regardless of the change to cost or life, indicating the output of the model is not overly sensitive to these inputs.

Scenarios 1, 2 and 3 maintain the same unit rates and expected ages, while changing the threshold percentage. In 87% of cases, the same trend was identified, indicating that the output is not overly sensitive to the threshold used.

Note, although the trend remained the same in most scenarios, the volume or value of assets at HROF did change significantly in some cases. However, this sensitivity analysis is interested in the trend of assets as they age rather than the absolute value of assets at HROF.

Overall, some asset classes show some sensitivity to the scenarios but in general the analysis demonstrates that the model is robust and producing a suitable and reliable metric.

Table 7: Summary of HROF Model Verification

2015-2020 TREND SUMMARY	**Scenario 1**	**Scenario 2 (expected)**	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Comments
Poles	+	-	-	-	-	-	Scenario 1 difference driven by age profile
Overhead Conductors	+	+	+	+	+	+	Good correlation
Underground Cables	+	+	+	-	+	+	Difference in target rate due to scope in unitised works
Distribution Transformers	-	-	+	-	-	-	Scenario 3 difference driven by age profile
Zone Substation Transformers	-	+	+	+	+	+	Scenario 1 difference driven by age profile
Distribution Switchgear	+	+	+	+	+	+	Good correlation
Zone Substation Switchgear	+	+	+	+	+	+	Good correlation
Protection, SCADA and Control	+	+	+	+	+	+	Good correlation
Service Lines	-	-	+	-	+	-	Large replacement program and impact to age profile
Network	+	+	+	+	+	+	Good correlation

6. Results of HROF Modelling: 2015 versus 2020

Figure 7 presents the results for the overall network of modelling the percentage of assets at High Risk of Failure, which shows the steady increase over the last 10 years continuing for the next regulatory period. Without expenditure the assets at HROF would increase from 18.9% to 28.1% of the asset base in 2020, but with forecast asset replacement expenditure levels this is being reduced to 23.3%. The level of assets at HROF is continuing to increase despite the forecast replacements.

The asset age profile shown in Figure 8 highlights the changes from the current profile to the forecast profile in six years. It demonstrates that the replacements do not balance out the increase in the number of assets in the HROF zone.

Figure 7: Assets at High Risk of Failure (value based) – Network

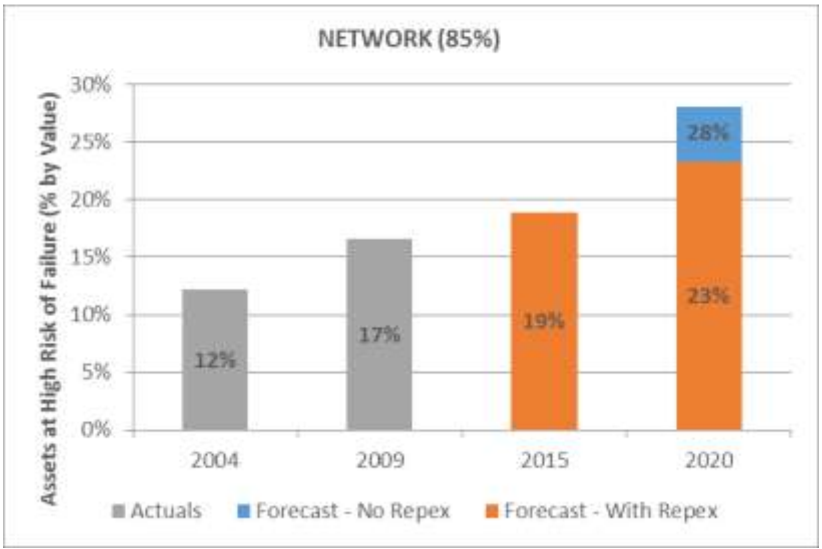
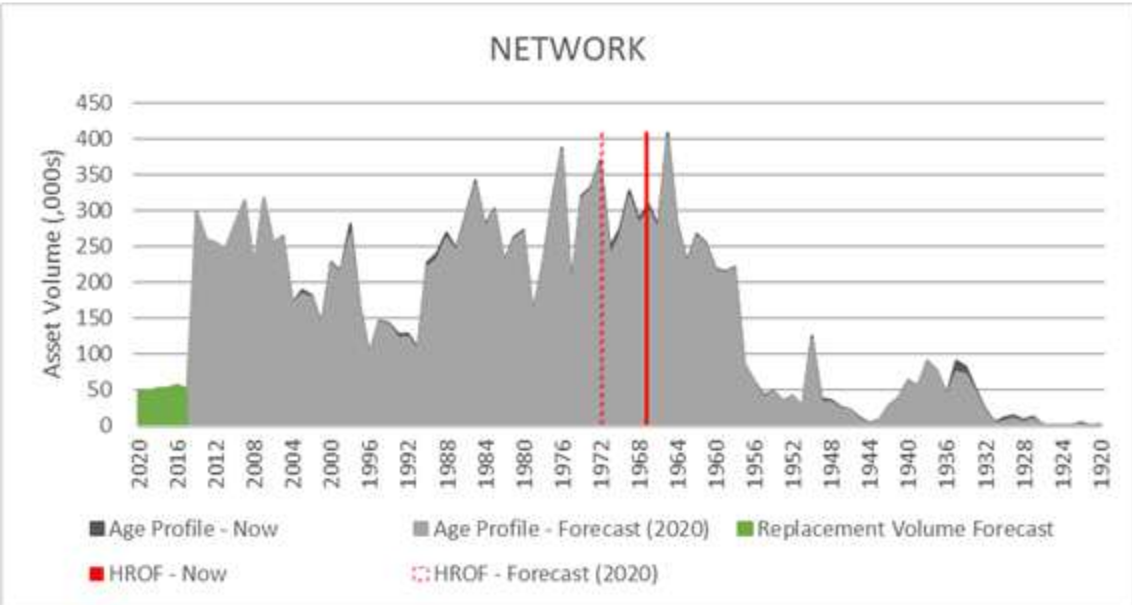


Figure 8: Asset Age Profile – Network



The chart does not include additional assets to be installed from 2015-20 for augmentation, customer initiated works or network performance drivers. This accounts for the significant difference in the level of assets shown in 2015-20 for replacement, compared to the level of assets for say 2006-14. This is exacerbated due to the units (meters) used for conductors and as most conductor is added to the network due to augmentation drivers. Also, since assets have a mixed length of expected life, the assets forecast to be replaced are spread across all periods of the network age profile.

Table 8 summarises the change in assets at HROF for the network between 2015 and 2020. Without any replacements, the assets reaching HROF increase by 9.1% or around $800m in replacement value. This equates to the level of asset replacement that would needed in order to maintain the level of assets at HROF. Instead, United Energy's overall strategy is to complement asset replacements with other strategies for maintaining reliability and network safety, including improving asset inspection and condition monitoring to enable assets to be replaced as close as possible to their end of life (ideally just before their imminent failure).

Table 8: Assets at HROF - Network

	Value of Assets ($M)	% at HROF by Value
Total Assets (2015)	$8741M	
Assets at HROF (2015)	$1654M	18.9%
New Assets reaching HROF 2015-2020	$803M	9.2%
Assets at HROF Forecast - No investment (2020)	$2457M	28.1%
HROF Assets replaced 2015-2020	$417M	4.8%
Assets at HROF Forecast - With investment (2020)	**$2,040M**	**23.3%**

* To provide a like for like comparison to the AER's analysis, not all subcategories were included, for example, bushings and OLTCs were not included in the zone substation transformers category, neither were pole top structures nor protection and control modelled.

While the network chart in Figure 7 shows the overall trend of assets at HROF, the network percentages are influenced by assets of high value. It is therefore more meaningful to consider the assets on a class basis. This is reflected in Table 9 which shows the percentage of assets at HROF on an asset class basis with and without the replacement expenditure forecast for 2020.

The Zone substation switchgear and transformers show the highest level of assets at HROF. However, the assets at HROF for both of these asset classes are being reduced to at least the 2015 level through the forecast replacement expenditure. The asset classes that are showing an increasing level of assets at HROF that are not maintained by the forecast replacement expenditure are poles, overhead conductors, underground cables, distribution switchgear, distribution transformers and protection and control.

The following sections give more detail on the assets that have been modelled by the AER:

- Poles
- Overhead Conductors
- Underground Cables
- Distribution Switchgear
- Distribution Transformers
- Zone Substation Switchgear
- Zone Substation Transformers
- Services

Table 9: Percentage of assets at HROF

	Actual			Forecast – Without Expenditure			Forecast – With Expenditure		
Asset Class	**2004**	**2009**	**2015**	**2020**	**Average decay rate 2004 to 2020 (% per year)**	**Average decay rate 2015 to 2020 (% per year)**	**2020**	**Average decay rate 2004 to 2020 (% per year)**	**Average decay rate 2015 to 2020 (% per year)**
Poles	10.7%	12.4%	7.1%	14.1%	0.2%	1.4%	11.0%	0.0%	0.8%
Overhead Conductors and Connectors	0.1%	16.8%	31.9%	47.6%	3.0%	3.2%	46.4%	2.9%	2.9%
Underground Cable	11.5%	14.7%	15.4%	20.0%	0.5%	0.9%	18.5%	0.4%	0.6%
Distribution Switchgear	21.5%	7.6%	15.7%	27.7%	0.4%	2.4%	22.4%	0.1%	1.3%
Distribution Transformers	2.7%	11.0%	6.0%	14.3%	0.7%	1.6%	8.3%	0.4%	0.5%
Zone Substation Switchgear	45.6%	7.6%	51.1%	60.2%	0.9%	1.8%	46.7%	0.1%	-0.9%
Zone Substation Transformers	23.5%	16.2%	33.9%	52.3%	1.8%	3.7%	36.6%	0.8%	0.5%
Services	9.9%	13.0%	4.7%	8.0%	-0.1%	0.6%	0.3%	-0.6%	-0.9%
ALL ASSETS	12.2%	16.6%	18.9%	28.1%	1.0%	1.8%	23.3%	0.7%	0.9%

6.1 Poles at High Risk of Failure

The current volume and value of poles at HROF and the forecast for 2020 with and without replacement expenditure is shown in Table 10. The value of pole assets at HROF is forecast to increase from 7.1% in 2015 to 11.0% in 2020 even with the forecast replacement expenditure. In order to maintain the value of poles at HROF the replacement expenditure would need to be in the order of $105m, more than double the amount forecast.

For the poles asset class, this difference between the value and volume based percentage is due to a significant portion of replacements targeting staked poles, which have a lower asset value than that of un-staked poles. These poles have a lower useful life of 25 years compared to wooden poles with a Useful Life of 70 years. These staked pole replacements are reflected in the Asset Class Age Profile, Figure 10, through the forecast drop in the number of assets installed between 1985 and 1995 in 2020.

The Asset Class Age Profile shows the average threshold for assets at HROF, which is based on the weighted average Useful Life of the pole assets. From this profile it can also be seen that the number of assets past the HROF threshold will increase significantly from 2020 onwards, given the large step increase in assets installed between 1960 and 1965, with the level of installation remaining high into the 1990's. In order to maintain the assets at HROF past 2020 will therefore require a significant increase in the number of replacements.

Table 10: Assets at HROF – Poles

	Value of Assets ($M)	% at HROF by Value
Total Assets (2015)	$1486M	
Assets at HROF (2015)	$106M	7.1%
New Assets reaching HROF 2015-2020	$104M	7.0%
Assets at HROF Forecast - No investment (2020)	$210M	14.1%
HROF Assets replaced 2015-2020	$46M	3.1%
Assets at HROF Forecast - With investment (2020)	$163M	11.0%

Figure 9: Forecast Percentage of Assets at HROF (by value) – Poles

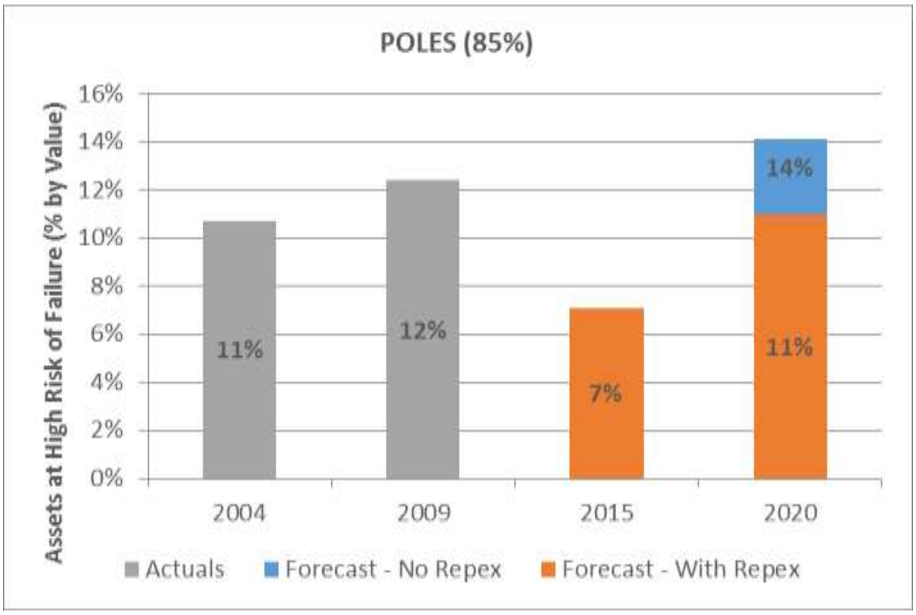
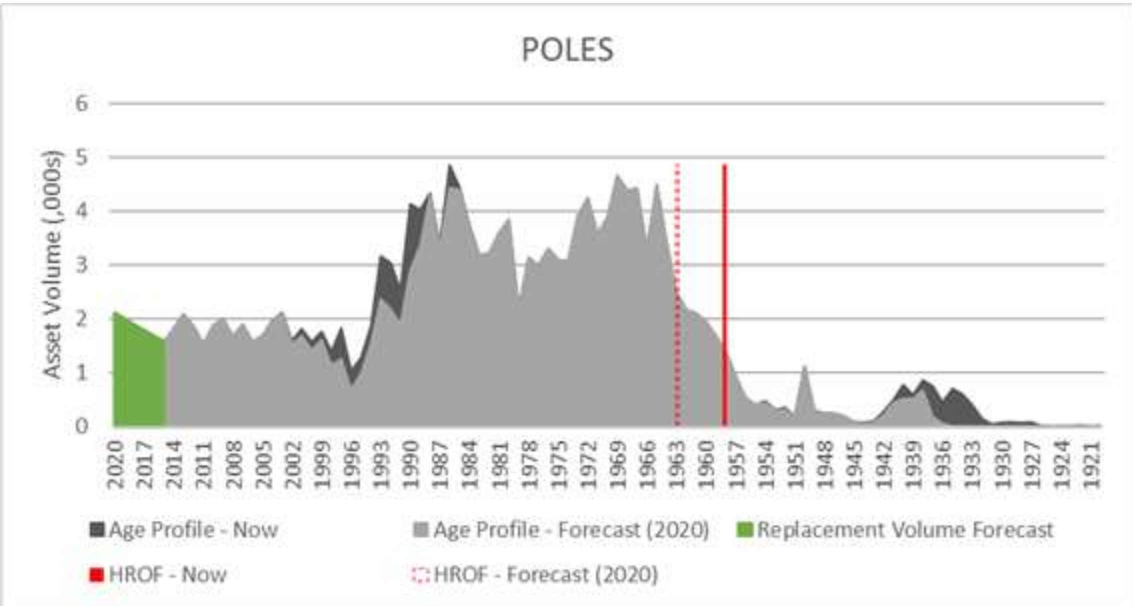


Figure 10: Asset Age Profile – Poles



The dark grey areas show where assets have been removed from the current age profile, and replaced with new assets (shown in green) in the period 2015 to 2020. This reduces the number of assets in specific years and results in the forecast age profile shown in grey. Where no blue is seen, there is no change between the current and forecast age profiles.

6.2 Overhead Conductors at High Risk of Failure

The current volume and value of overhead conductors at HROF and the forecast for 2020 with and without replacement expenditure is shown in Table 11. The value based percentages are also reflected in Figure 11. The volume and value of assets at HROF is significantly increasing over the next 5 years, and even with the replacement forecasts targeting the oldest assets that number of assets at HROF is not being maintained. The rate of increase in aging assets cannot be matched by replacements.

Despite the relatively low unit cost of the conductors (averaging around $65 per unit), the large volume of these assets makes these a high cost item for replacement. Maintaining the assets at HROF by 2020 to the 2015 level, would equate to a cost in the order of $260m. The $20m value of assets replaced is reflective of the strategic approach for overhead cables which is to repair assets identified with faults or defects, with replacement only where necessary. This is supported by condition assessment of assets on a cyclic basis and using pole top and thermal camera inspections. The low percentage reduction of assets (1.2%) reflects this strategy.

Table 11: Assets at HROF – Overhead Conductors

	Value of Assets ($M)	% at HROF by Value
Total Assets (2015)	$1670M	
Assets at HROF (2015)	$532M	31.9%
New Assets reaching HROF 2015-2020	$264M	15.8%
Assets at HROF Forecast - No investment (2020)	$795M	47.6%
HROF Assets replaced 2015-2020	$20M	1.2%
Assets at HROF Forecast - With investment (2020)	$775M	46.4%

Figure 11: Forecast Percentage of Assets at HROF (by value) – Overhead Conductors

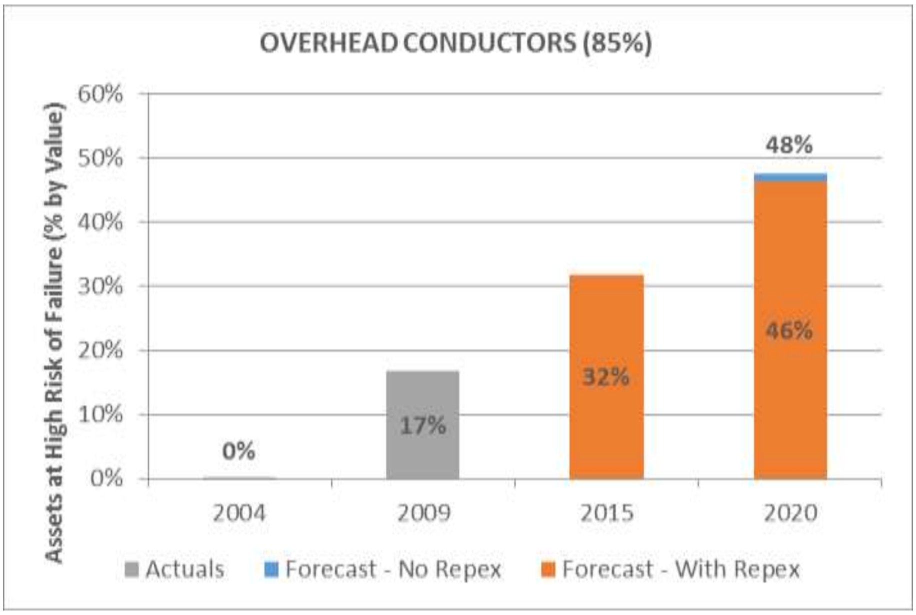
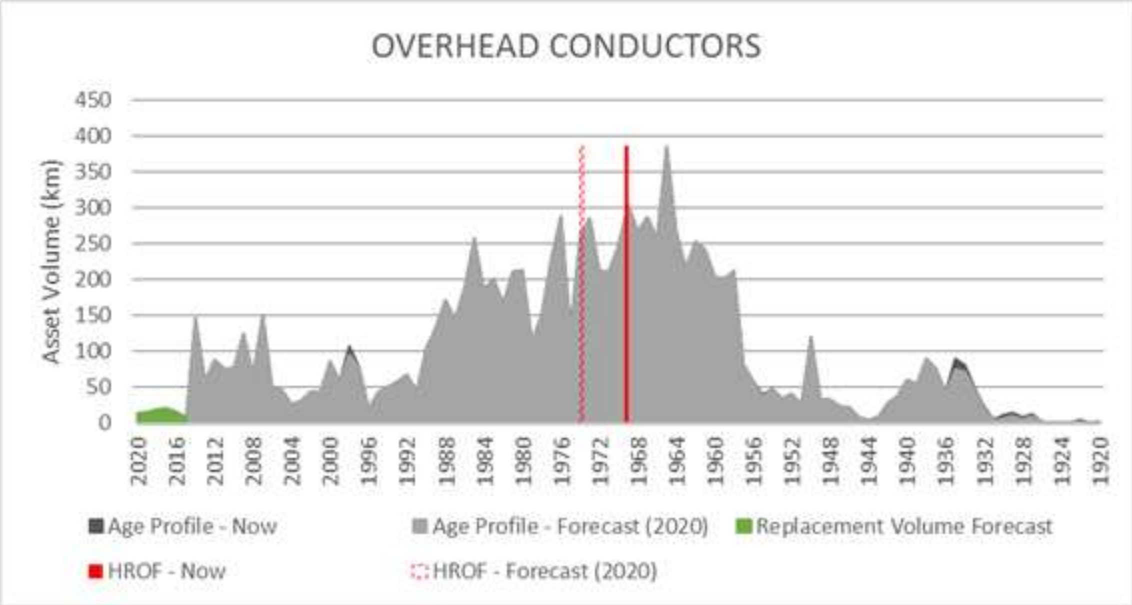


Figure 12: Asset Age Profile – Overhead Conductors



The dark grey areas show where assets have been removed from the current age profile, and replaced with new assets (shown in green) in the period 2015 to 2020. This reduces the number of assets in specific years and results in the forecast age profile shown in grey. Where no blue is seen, there is no change between the current and forecast age profiles.

It should also be noted that there are initiatives / projects in place that require replacements for non-age related reasons:

HV ABC replacements: The non-metallic screened HV ABC is showing a type fault and needs to be replaced to mitigate bushfire risk and detrimental impacts to network performance. The HV ABC is planned to be replaced with the latest technical standard (metallic screened ABC) or in combination with bare overhead and underground cable depending on a case by case assessment of efficiency.

These projects will effectively further increase the assets at HROF, as the model assumes that all replacement expenditure will target the oldest assets. It should be noted that while the HROF model assumes that replacements are made to the oldest assets, the sheer volume of HV ABC assets being replaced has resulted in a significant number of asset replacements being outside of the HROF zone.

6.3 Underground Cables at High Risk of Failure

The current volume of underground cables at HROF and the forecast for 2020 with and without replacement expenditure is shown in Table 12. The value based percentages are also reflected in Figure 13. The value of assets at HROF is forecast to increase between 2015 and 2020, with the forecast asset replacements having little impact on reducing the percentage. As with overhead conductors, this minimal impact is due to the strategic approach for underground cables being to repair rather than replace where possible.

It should be noted that the Underground Cable class includes both actual cable lengths, with volume measured in cable length (m), and related assets such as pits and pillars where actual number of assets are used. This makes the volume based figures difficult to interpret given the high cable lengths. The value based percentages are more meaningful in this case.

Table 12: Assets at HROF – Underground Cables

	Value of Assets ($M)	% at HROF by Value
Total Assets (2015)	$2523M	
Assets at HROF (2015)	$389M	15.4%
New Assets reaching HROF 2015-2020	$115M	4.5%
Assets at HROF Forecast - No investment (2020)	$504M	20.0%
HROF Assets replaced 2015-2020	$34M	1.3%
Assets at HROF Forecast - With investment (2020)	$470M	18.6%

Figure 13: Forecast Percentage of Assets at HROF (by value) – Underground Cables

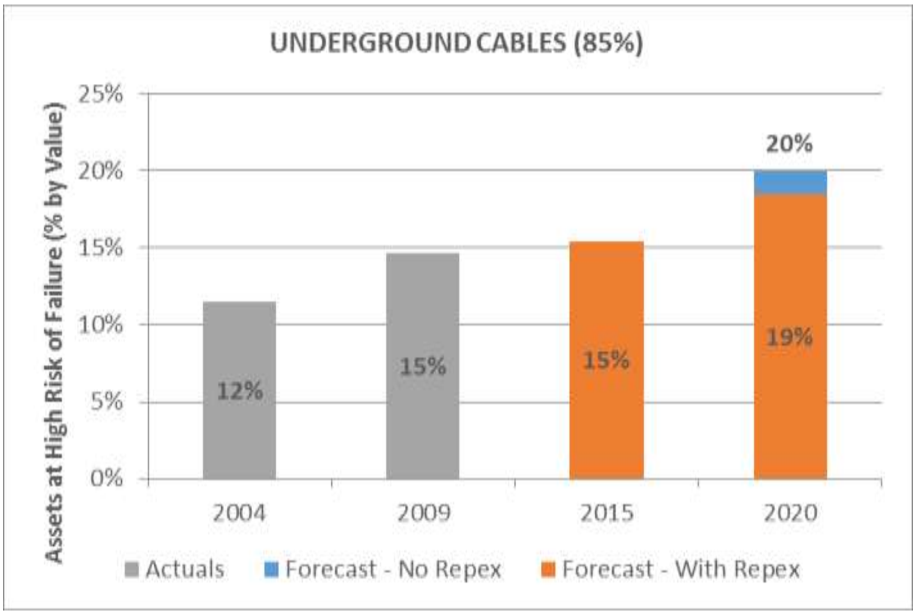
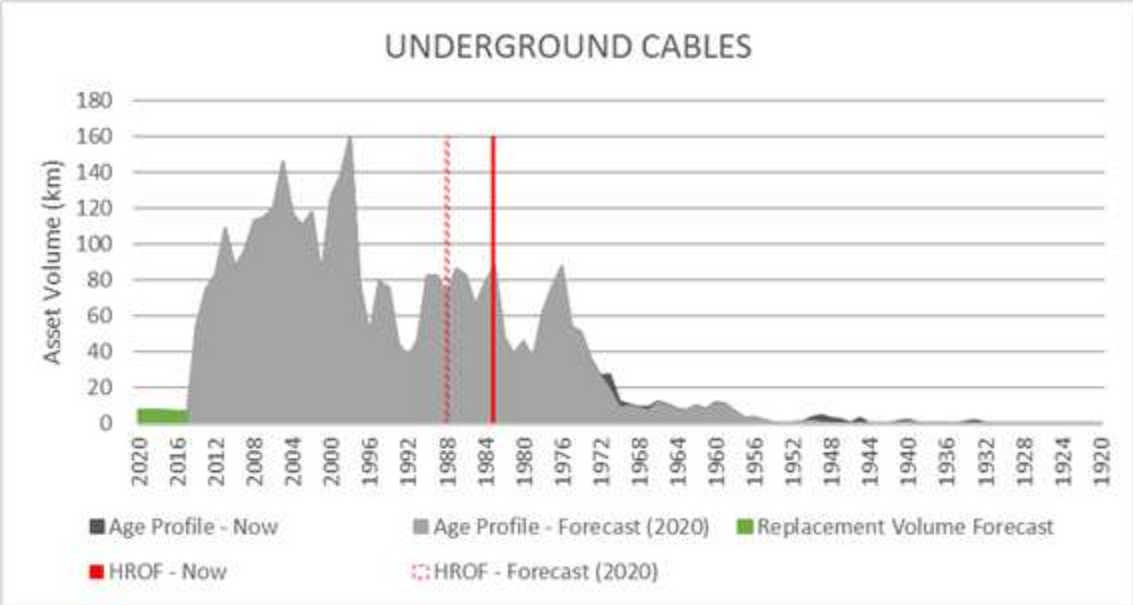


Figure 14: Asset Age Profile – Underground Cables



The dark grey areas show where assets have been removed from the current age profile, and replaced with new assets (shown in green) in the period 2015 to 2020. This reduces the number of assets in specific years and results in the forecast age profile shown in grey. Where no blue is seen, there is no change between the current and forecast age profiles.

The model assumes that all replacements are made to assets at the end of the age profile i.e. the oldest assets. There are some initiatives that are in place that are not age related that will effectively increase the number of assets forecast at HROF. These projects are:

Doncaster Pillar replacement project: Doncaster style pillars were built in the late 1970's and 1980's by the then City of Doncaster & Templestowe electricity supply department. Doncaster style pillars are of an all metal type construction with the lid hinging at the back of its base. In most instances the base of these pillars may contain asbestos and therefore pose a public safety risk and are progressively being replaced. Pillars are being replaced with a fully buried cable system bringing them up to current construction standards. A proactive program (which commenced 2013/14) for the removal of all these pillars and replacement with pits is detailed in the document titled "Doncaster Pillar Replacement Strategy". There were originally 1700 of these pillars in service, as at November 2014, 820 have been replaced, leaving approximately 880 still to be replaced.

Cable rejuvenation program: United Energy is undertaking a trial of the Cable Cure cable rejuvenation process, which is designed to reverse the effects of water treeing and significantly extend the life of XLPE cable. A water reactive compound is injected directly into the conductor strands. The fluid diffuses from the conductor strands into the insulation material reacting with the water held in the cable. The process rejuvenates cable insulation resulting in improved dielectric strength. If the trial proves to be successful this will allow cable replacement capital to be deferred.

6.4 Distribution Switchgear at High Risk of Failure

The current volume and value of distribution switchgear at HROF and the forecast for 2020 with and without replacement expenditure is shown in Table 13. The value based percentages are also reflected in Figure 15. The number of assets at HROF has been steadily increasing over the last ten years and is forecast to continue to increase for the next 20 years and more as reflected in the asset age profile (Figure 16). Even with the forecast replacement expenditure the percentage of assets at HROF is forecast to increase from 16% to 22%. To maintain the assets at HROF to 2015 levels and therefore maintain reliability profiles, approximately double the amount of replacement expenditure would be required.

Table 13: Assets at HROF – Distribution Switchgear

	Value of Assets ($M)	% at HROF by Value
Total Assets (2015)	$871M	
Assets at HROF (2015)	$136M	15.7%
New Assets reaching HROF 2015-2020	$105M	12.1%
Assets at HROF Forecast - No investment (2020)	$242M	27.7%
HROF Assets replaced 2015-2020	$46M	5.3%
Assets at HROF Forecast - With investment (2020)	$195M	22.4%

Figure 15: Forecast Percentage of Assets at HROF (by value) – Distribution Switchgear

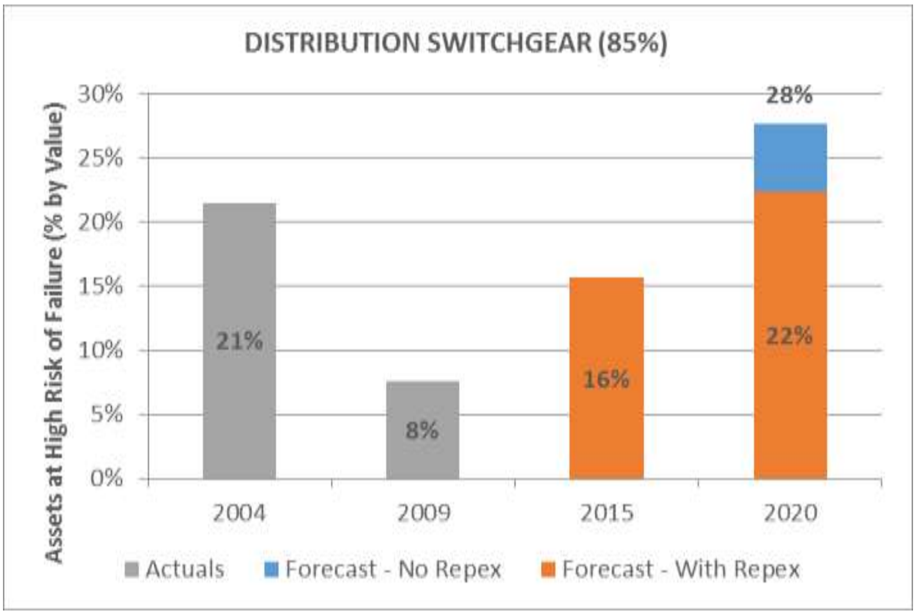
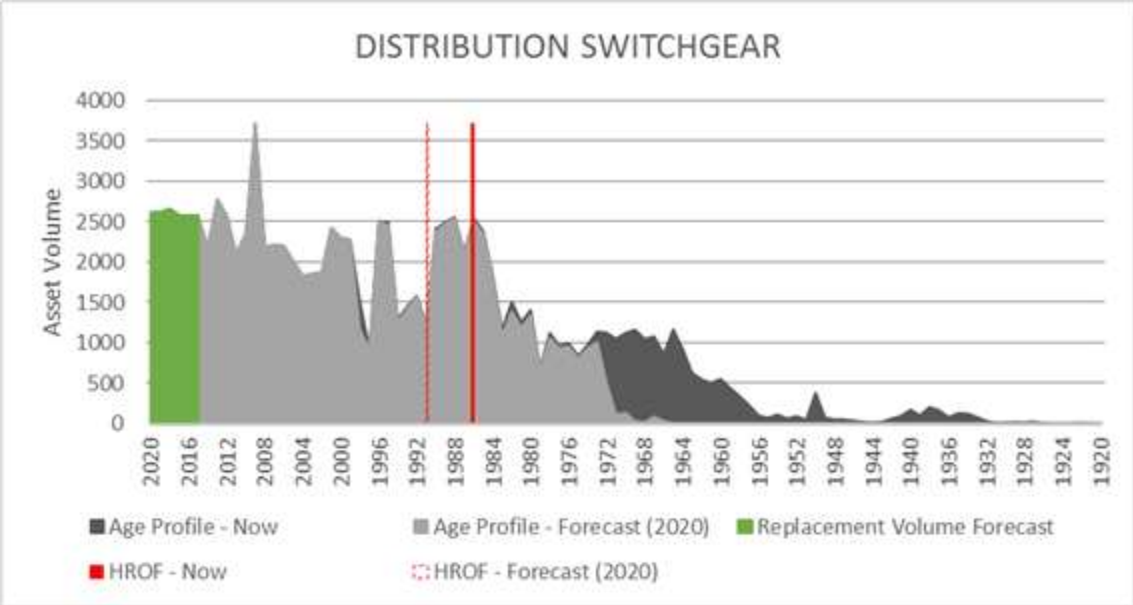


Figure 16: Asset Age Profile – Distribution Switchgear



The dark grey areas show where assets have been removed from the current age profile, and replaced with new assets (shown in green) in the period 2015 to 2020. This reduces the number of assets in specific years and results in the forecast age profile shown in grey. Where no blue is seen, there is no change between the current and forecast age profiles.

6.5 Distribution transformers at High Risk of Failure

The current volume and value of distribution transformers at HROF and the forecast for 2020 with and without replacement expenditure is shown in Table 14. The value based percentages are also reflected in Figure 17. The value of distribution transformers at HROF is forecast to marginally increase from 2015 to 2020 from 6% to 8.3% with replacement expenditure, with the forecast replacements going a fair way to maintaining assets at HROF.

The historical trend of assets at HROF shows a significant drop between 2009 and 2014. This is due to the distribution transformer replacement program that was undertaken in 2011 to remove transformers that were heavily loaded. This has helped to enable the percentage of assets at HROF to be maintained to closer to 2015 levels.

Table 14: Assets at HROF – Distribution Transformers

	Value of Assets ($M)	% at HROF by Value
Total Assets (2015)	$244M	
Assets at HROF (2015)	$15M	6.0%
New Assets reaching HROF 2015-2020	$20M	8.2%
Assets at HROF Forecast - No investment (2020)	$35M	14.3%
HROF Assets replaced 2015-2020	$14M	5.9%
Assets at HROF Forecast - With investment (2020)	$20M	8.3%

Figure 17: Forecast Percentage of Assets at HROF (by value) – Distribution Transformers

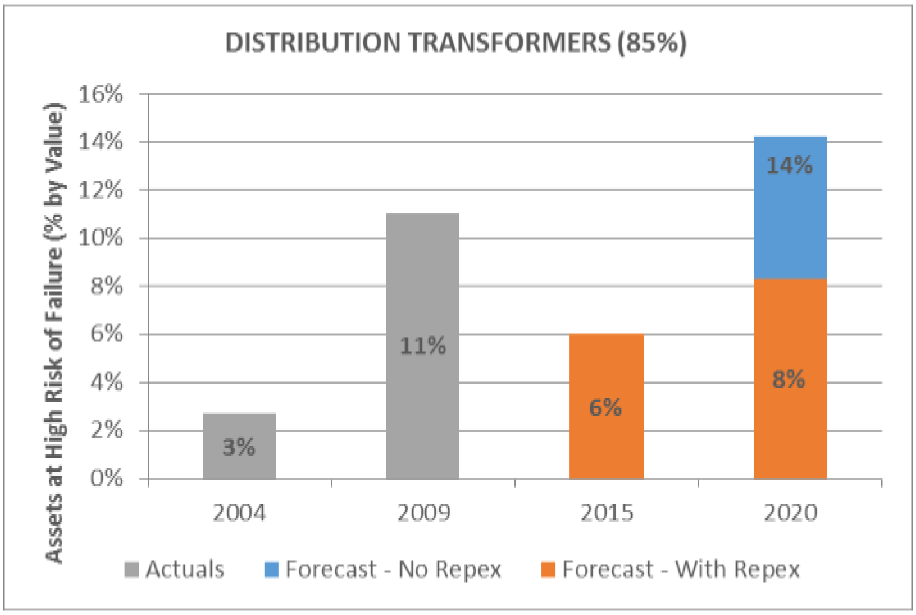
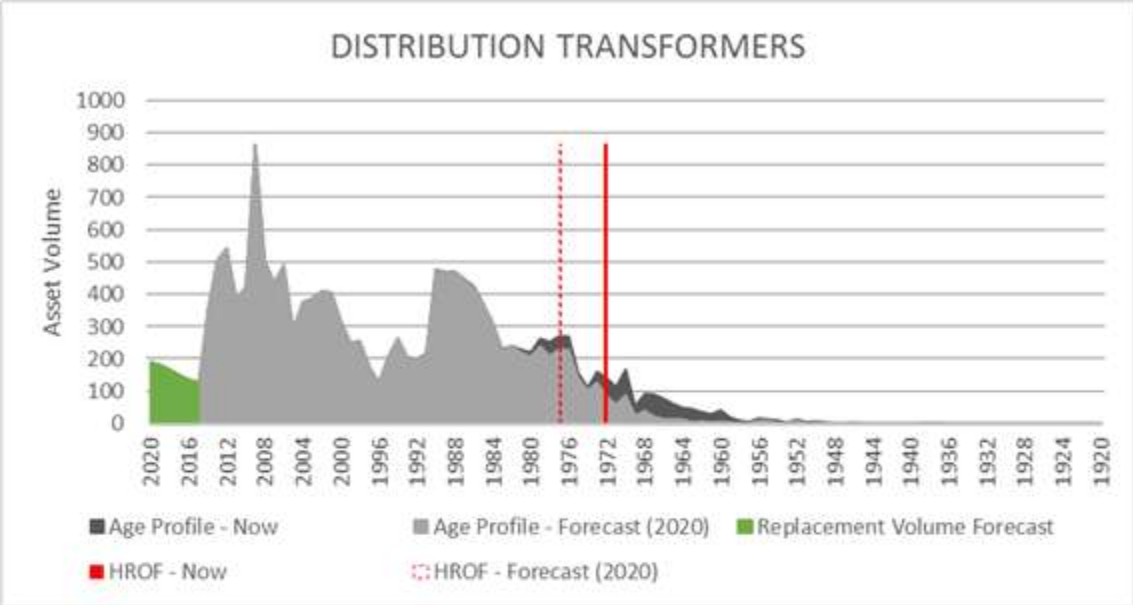


Figure 18: Asset Age Profile – Distribution Transformers



The dark grey areas show where assets have been removed from the current age profile, and replaced with new assets (shown in green) in the period 2015 to 2020. This reduces the number of assets in specific years and results in the forecast age profile shown in grey. Where no blue is seen, there is no change between the current and forecast age profiles.

6.6 ZSS Switchgear at High Risk of Failure

The current volume and value of Zone Substation Switchgear at HROF and the forecast for 2020 with and without replacement expenditure is shown in Table 15. The value based percentages are also reflected in Figure 19. The value of ZSS switchgear at HROF is forecast to decrease between 2015 and 2020 due to the forecast replacement expenditure replacing a large amount of old assets in this category. It should be noted that due to the criticality of these assets the forecast replacement programs is based on thorough condition assessments. It should also be noted that these assets are typically not able to be replaced one at a time and are usually replaced by undertaking the replacement at the zone substation a bus at a time.

Table 15: Assets at HROF – ZSS Switchgear

	Value of Assets ($M)	% at HROF by Value
Total Assets (2015)	$222M	
Assets at HROF (2015)	$113M	51.1%
New Assets reaching HROF 2015-2020	$20M	9.1%
Assets at HROF Forecast - No investment (2020)	$134M	60.2%
HROF Assets replaced 2015-2020	$30M	13.5%
Assets at HROF Forecast - With investment (2020)	$104M	46.7%

Figure 19 shows a significant decrease in the percentage by value of assets at HROF in 2009. The reason for this was due to a number of asset replacements (zone substation refurbishments and augmentations) decreasing the number of assets at HROF combined with significant growth that increased the asset base value and therefore further decreased the percentage of assets at HROF by a percentage of total value.

The increase in assets at HROF in 2015 is a result of the AERs asset category reporting requirements resulting in the inclusion of some additional assets into the 2015 age profile that were not included in earlier age profiles, adding both additional value and additional old assets. This creates a difference in the basis of the forecast in this category between the current and forecast data compared to the historic data. However, it is important to note that the forecast data is calculated on the same basis as the current (2015) data and therefore provides a useful insight into the future state of the network.

Figure 19: Forecast Percentage of Assets at HROF (by value) – ZSS Switchgear

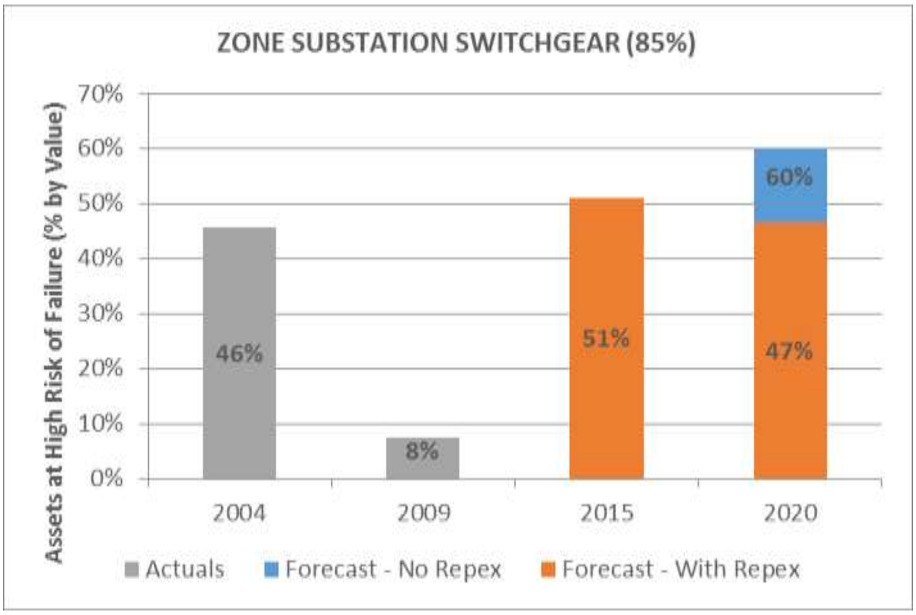
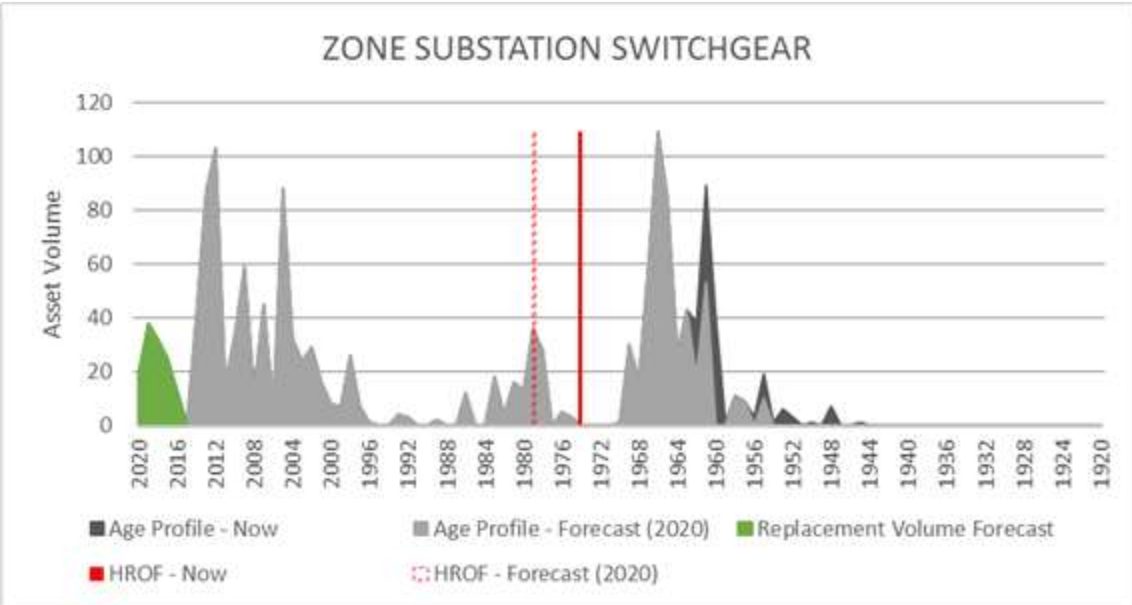


Figure 20: Asset Age Profile – ZSS Switchgear



The dark grey areas show where assets have been removed from the current age profile, and replaced with new assets (shown in green) in the period 2015 to 2020. This reduces the number of assets in specific years and results in the forecast age profile shown in grey. Where no blue is seen, there is no change between the current and forecast age profiles.

6.7 ZSS Transformers at High Risk of Failure

The current volume and value of Zone Substation transformers at HROF and the forecast for 2020 with and without replacement expenditure is shown in Table 16. The value based percentages are also reflected in Figure 21. The value of assets at HROF is forecast to decrease between 2015 and 2020 with replacement expenditure.

The Zone substation transformers are critical elements in the distribution network because of their high replacement cost, their strategic impact on customer supply and their long lead time for repair or replacement. Failure of a transformer can result in explosions and fires causing substantial damage to the neighbouring equipment and possibly the entire station, as well as interruption in supply to customers. The replacements forecast is driven by condition monitoring and prudent risk management.

Table 16: Assets at HROF – ZSS Transformers

	Value of Assets ($M)	% at HROF by Value
Total Assets (2015)	$301M	
Assets at HROF (2015)	$102M	33.9%
New Assets reaching HROF 2015-2020	$56M	18.4%
Assets at HROF Forecast - No investment (2020)	$157M	52.3%
HROF Assets replaced 2015-2020	$47M	15.7%
Assets at HROF Forecast - With investment (2020)	$110M	36.6%

Figure 21 shows a decrease in the percentage by value of assets at HROF in 2009. The reason for this was due to a number of asset replacements (zone substation refurbishments and augmentations) decreasing the number of assets at HROF combined with significant growth that increased the asset base value and therefore further decreased the percentage of assets at HROF by a percentage of total value.

The increase in assets at HROF in 2015 and again in 2020 is a result of the progression of the threshold past peaks in the age profile, increasing the number of assets at HROF more quickly than assets are replaced.

Figure 21: Forecast Percentage of Assets at HROF (by value) – ZSS Transformers

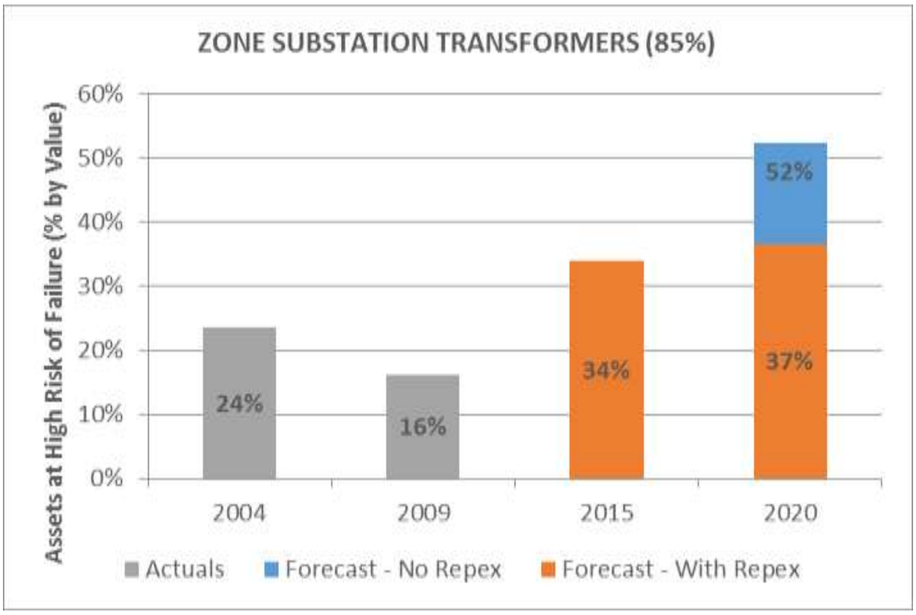
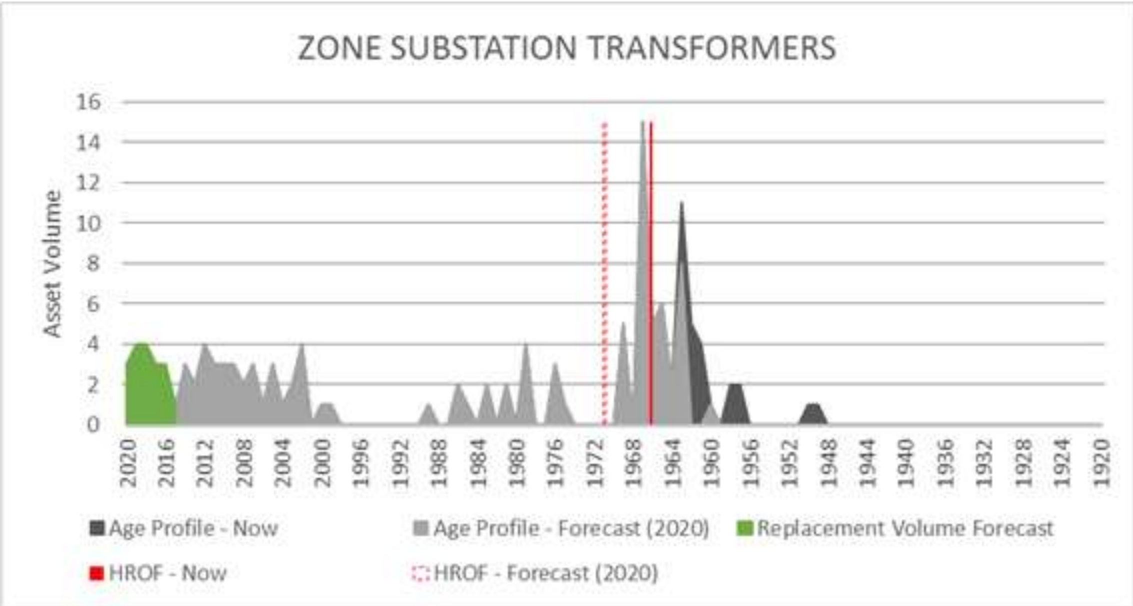


Figure 22: Asset Age Profile – ZSS Transformers



The dark grey areas show where assets have been removed from the current age profile, and replaced with new assets (shown in green) in the period 2015 to 2020. This reduces the number of assets in specific years and results in the forecast age profile shown in grey. Where no blue is seen, there is no change between the current and forecast age profiles.

6.8 Services at High Risk of Failure

The current volume and value of services at HROF and the forecast for 2020 with and without replacement expenditure is shown in Table 17. The value based percentages are also reflected in Figure 23. The value of assets at HROF is forecast to reduce from 2015 to 2020 and has reduced significantly from 2009. This decrease is due to a substantial replacement program that is being undertaken which commenced in 2010 and is forecast to be completed in 2016. This is a safety driven program that replaces Neutral screened cables that have resulted in an increased number of electric shock incidents to the public.

Table 17: Assets at HROF – Services

	Value of Assets ($M)	% at HROF by Value
Total Assets (2015)	$186M	
Assets at HROF (2015)	$9M	4.7%
New Assets reaching HROF 2015-2020	$6M	3.2%
Assets at HROF Forecast - No investment (2020)	$15M	8.0%
HROF Assets replaced 2015-2020	$14M	7.7%
Assets at HROF Forecast - With investment (2020)	$1M	0.3%

Figure 23: Forecast Percentage of Assets at HROF (by value) – Services

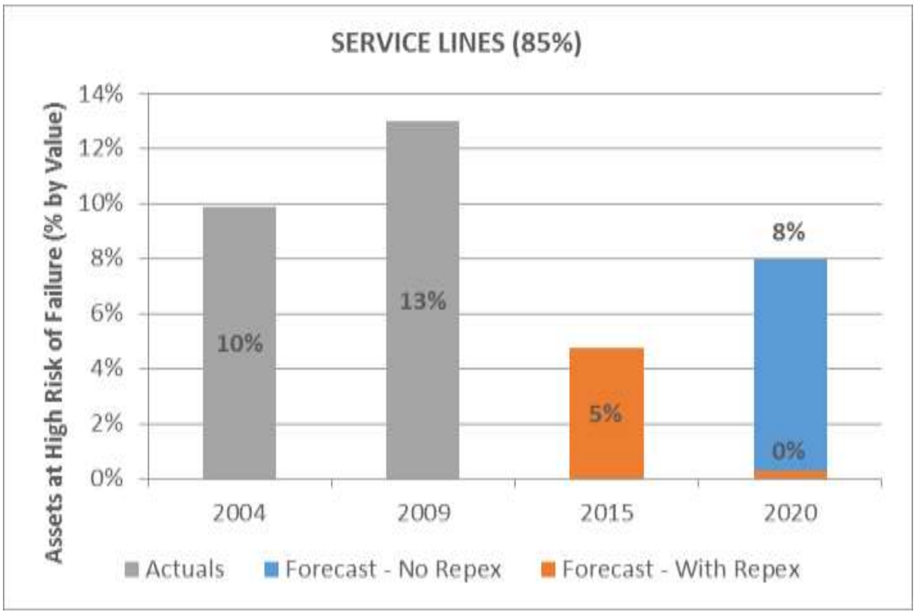
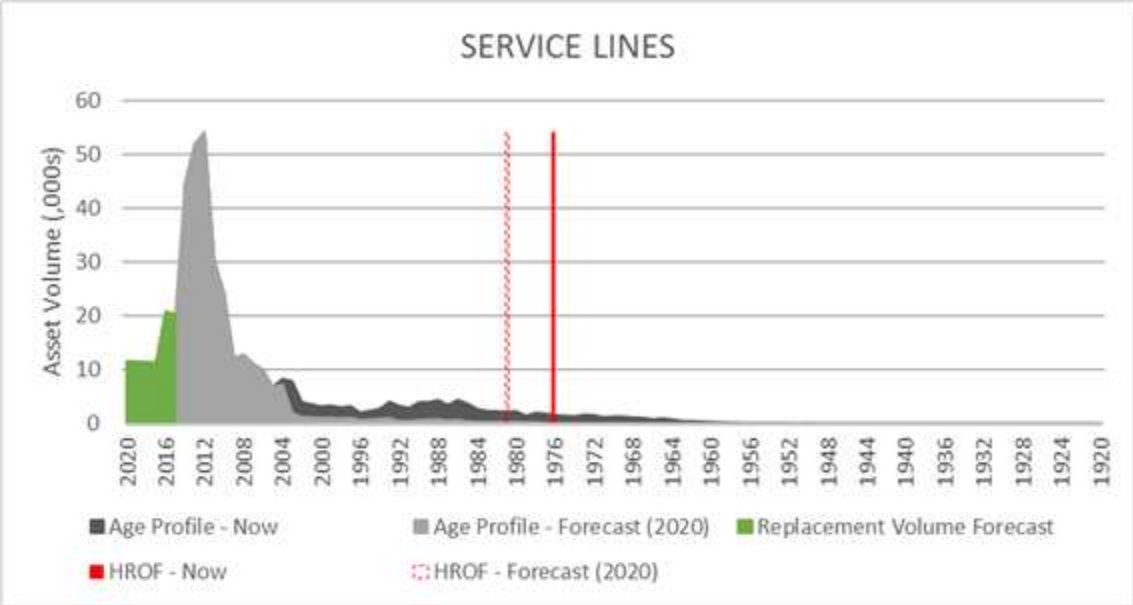


Figure 24: Asset Age Profile – Services



The dark grey areas show where assets have been removed from the current age profile, and replaced with new assets (shown in green) in the period 2015 to 2020. This reduces the number of assets in specific years and results in the forecast age profile shown in grey. Where no blue is seen, there is no change between the current and forecast age profiles.

7. Validation

7.1 Validation Methodology

In order to test that the HROF metric will measure the risk of defects and failures for the asset classes, United Energy has sought to use historic data to determine how asset performance relates to the percentage of assets at HROF. The different asset management data available to be used in the validation, and the limitations of each measure, is discussed in the following sections.

By validating the HROF model against historic performance, confidence can be gained for using the model as an indicator of future underlying asset health and overall network health.

7.1.1. Notifications

United Energy has collected SAP notification data to record damage, defects and notable information about assets in the network since 1999. Notifications are typically raised during an inspection or maintenance. A notification is specific to a piece of information against a specific piece of equipment. Therefore, a single piece of equipment may attract multiple notifications should multiple defects, damage or pieces of information be present against it.

When a notification against equipment is created it is assigned a damage code and priority. This indicates the type of defect or information for the equipment and, to a degree, the severity/importance of the defect or information. Depending on asset class, damage code and priority a notification will have varying outcomes. For some asset classes notifications primarily drive replacements, whereas in other classes notifications will drive corrective or preventative maintenance and feed into condition assessments.

In asset classes for which replacement is driven by notifications it is common for the trend in lower priority notifications (P3) to act as lead indicators for higher priority notifications (P1 and P2). Lower priority notifications rarely result in proactive replacement in these cases, and would only be rectified should suitable efficiency gain be available (asset involved in a project for example).

Most notifications are raised for defects, and for this reason there is a correlation between assets which are wearing out and the volume of notifications raised. This is observed regardless of whether the replacement is driven by notifications or not. Therefore, notifications have been used as a key indicator for the accuracy of the HROF model. It is expected that as the proportion of assets at HROF increase so should the volume of notifications and vice versa.

The key relationship trends analysed for notifications are:

	Charts	Assessment
1	Priority 1, 2 and 3 notifications vs percentage of Assets at HROF	General trends over period measured (less focus on P3)
2	Notifications vs replacements	Observed to establish relationship between notifications and replacements – not a key indicator for validation

7.1.2. Replacements and Repex

As discussed above, replacements can be driven by notifications of defects, but they may also be driven by specific targeted programs, where assets are replaced for safety reasons or following trigger events such as changed legislation, extreme heat, or storms. For this reason looking at the volume of replacements for an asset class may not always show clear trends with assets at HROF.

The total Repex per asset class can also be heavily affected by the type of assets being replaced in any particular year. For example, replacing assets with a different technology, or a change in the mix of assets replaced between high volume but low cost assets and low volume but high cost assets may distort the usefulness of this metric.

In general the volume of replacements and replacement capex is expected to increase in proportion to the percentage of assets at HROF increases. This assumes asset replacement is efficient and hence assets are replaced at failure, or as close as practicable to failure. It is important to note that United Energy has been benchmarked against other distribution service providers by the AER and found to be one of the most efficient providing confidence the allocation of Repex has historically been efficient.

The key relationship trends analysed for notifications are:

	Charts	Assessment
3	Replacements vs percentage Assets at HROF	General trends over period measured
4	Repex vs percentage Assets at HROF	General trends over period measured

7.1.3. Reliability performance

United Energy has developed a network reliability assessment report that undertakes analysis of asset performance for the overall network and asset classes. The reliability data used in this report is SAIFI related to equipment failure, as that is most reflective of asset condition and risk of failure. This is used to demonstrate the correlation between the performance of the assets and the assets at HROF over a number of years. The equipment related SAIFI can be correlated with asset failures for both historical and forecast to allow an assessment of how the performance can be related to the assets at HROF.

In many asset classes the management strategy is for proactive replacement, with assets being replaced based on condition and prior to failure. The number of assets actually failing is therefore purposefully managed to remain low for these asset classes, which makes trends in SAIFI, outages or asset failures difficult to ascertain and not useful for predictive purposes.

SAIFI and outages have been considered for assets that are managed under a run to failure regime.

The key relationship trends analysed for notifications are:

	Charts	Assessment
5	SAIFI vs % Assets at HROF	General trend over measure period where SAIFI is applicable i.e. there is sufficient data from failures
6	Outages vs % Assets at HROF	General trend over measure period where outages are applicable i.e. there is sufficient data from failures

7.1.4. Validation Analytics

Each asset class has been assessed for trends in the six chart described in the section above to determine whether historical data shows a relationship. This has been collated in a validation summary table to assess the overall correlation of assets at HROF with these measures to assess if it is a useful predictive tool.

7.2 Network

7.2.1. Background Data

The United Energy network is made up of a variety of different asset types that have different characteristics, management regimes and replacement costs. To simplify the analysis of the network, this validation section considers a subset of these assets summarised into eight asset categories:

1. Poles
2. Overhead conductors
3. Underground cables
4. DSS Switchgear
5. DSS Transformers
6. ZSS Switchgear
7. ZSS Transformers
8. Services.

These eight asset classes represent the assets that have been modelled by the AER and in general are associated with the most risk of failure, reliability or safety. Pole top structures, public lighting, and SCADA and protection are not included on an individual asset class basis, but do form part of the overall network analysis.

Each asset category has its own management strategy, with most assets being pro-actively replaced based on asset condition, but some assets being let run to failure due to an inability to monitor condition or economic efficiency.

The following sections show the trends for the network as a whole.

7.2.2. Validation Analytics

Figure 25: Notifications vs. Assets at HROF - Network

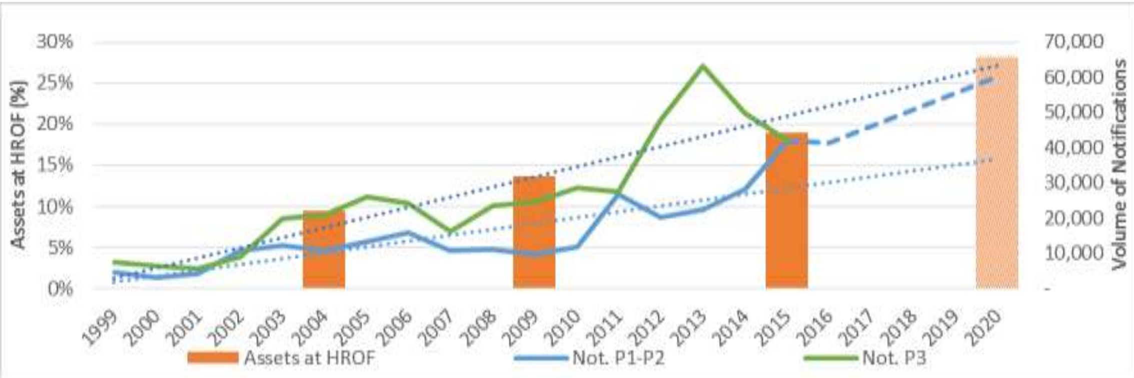


Figure 25 shows the historical trends of notifications and assets at HROF for the network. The chart shows a strong correlation between the number of notifications and the percentage of assets at HROF, where HROF is based on the weighted value of network assets. The data clearly show that there is an increasing trend of notifications as the percentage of HROF increases.

Figure 26 shows a strong correlation between the level of replacement capex and the proportion of assets at high risk of failure. It is also noticeable that even with the increase in replacement capex, the proportion of assets at high risk of failure is also increasing.

Figure 28 shows that as the number of assets at HROF has increased since 2004, the performance of the network has deteriorated.

The trends shown in these charts are reflective of the large number of assets that were commissioned during the period of network expansion during the 1960s and 1970s approaching the end of their expected lives. Figure 8 in Section 6 shows the network age profile which reinforces this issue.

Figure 26: Replacement vs. Assets at HROF - Network

Figure 27: High Priority Notifications vs. Replacement - Network

Figure 28: SAIFI / Outages vs. Assets at HROF - Network

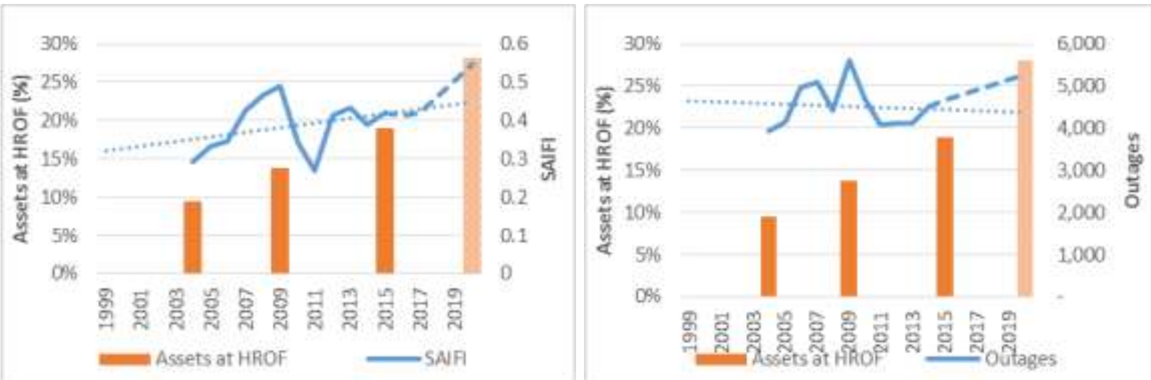


Table 18: Validation Analysis Summary – Network

Validation Test	Correlation
Notifications vs. Assets at HROF	✓
Replacement (Vol) vs. Assets at HROF	✓
Replacement ($) vs. Assets at HROF	✓
High Priority Notifications vs. Replacement (Vol)	(✓)
SAIFI vs. Assets at HROF	✓
Outages vs. Assets at HROF	✗

✓	Correlation of data
(✓)	Correlation when knowledge of historical asset management / performance considered
✗	No correlation of data but justified
N/A	Insufficient data to allow correlation to be observed or not applicable to the asset class

Table 18 presents a summary of the validation assessment for the overall network. Assets at HROF correlates strongly with the key metrics of asset health, supporting its suitability as an indicator of current and future underlying network health.

7.3 Poles

7.3.1. Background Data

The pole assets class consists of wooden, concrete and steel poles for sub transmission, LV and HV. Staked wooden poles are also included.

7.3.2. Validation Analytics

As shown in Figure 29, the trend of the number of notifications for poles is increasing. This correlates with the historic and forecast percentage of assets at HROF. The HROF has decreased in 2015 primarily due to an increase in pole staking driven by a changed approach to the management of the asset class implemented in 2013 and an increased level of replacement during the past six years.

When poles are staked they are transferred to a separate age profile with its own characteristics, and effectively become 'new' poles again. The pole staking practices changed in 2012/13 as reflected by increased replacements in Figure 30. This has resulted in a decreased number of assets at HROF in 2015. Despite this, forecasting on the same basis and using conservative replacement assumptions in the modelling, the percentage of HROF assets is forecast to increase during the next 5 years. This is supported by the age profile, shown in Figure 10 of section 6.1, and the trends of the notifications.

As shown in Figure 31, there is a strong correlation between the combined P1 and P2 notifications and the number of poles replaced. This analysis also identified the strong relationship between P1 and 2 notifications with P3 notifications with a delay of approximately 3 to 4 years. This shows P3s to be lead indicator for P1 and P2 level notifications and the need to replace or stake poles.

Since poles are located publicly accessible areas, failures can have significant safety consequences. As a result pole are a managed asset with the number of failures kept very low. Additionally, a pole failure does not necessarily result in an outage. Therefore, SAIFI and outages are not good indicators of the number of assets reaching end of life or the performance of the asset fleet and reliability has not been considered for this asset class.

Figure 29: Notifications vs. Assets at HROF - Poles

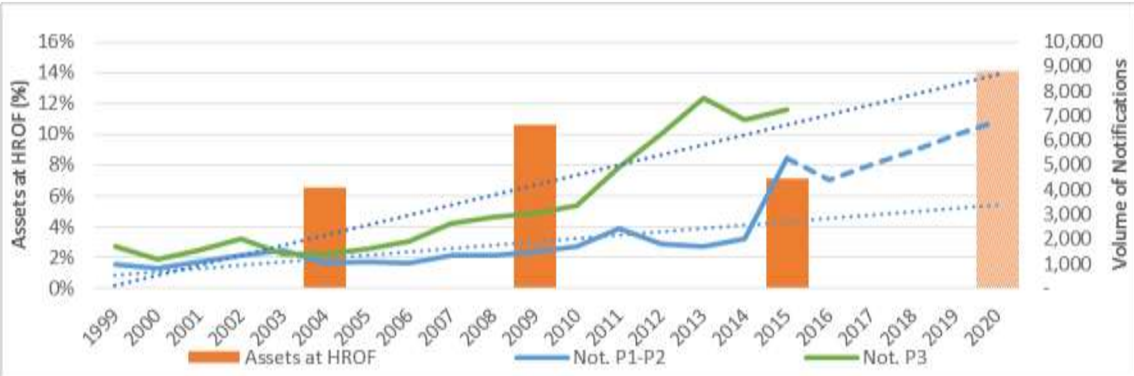


Figure 30: Replacement vs. Assets at HROF - Poles

Figure 31: High Priority Notifications vs. Replacement - Poles

Figure 32: SAIFI / Outages vs. Assets at HROF - Poles

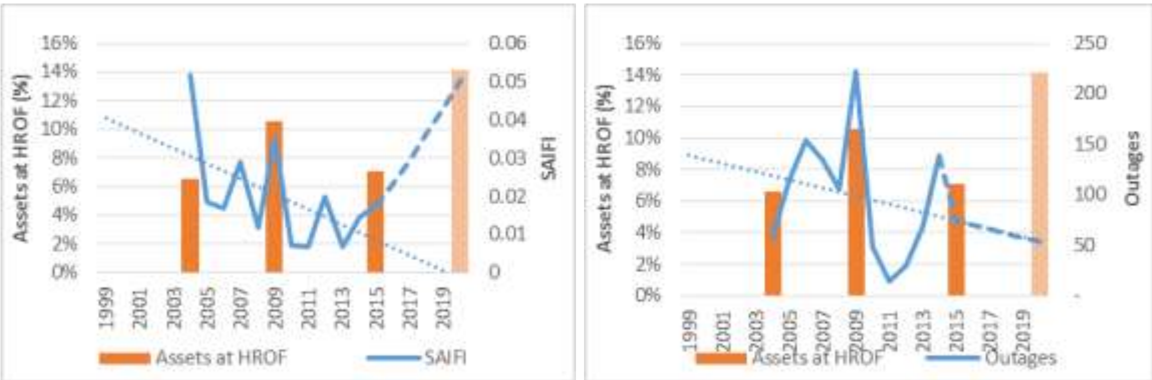


Table 19: Validation Analysis Summary - Poles

Validation Test	Correlation
Notifications vs. Assets at HROF	(✓)
Replacement (Vol) vs. Assets at HROF	(✓)
Replacement ($) vs. Assets at HROF	(✓)
High Priority Notifications vs. Replacement (Vol)	✓
SAIFI vs. Assets at HROF	N/A
Outages vs. Assets at HROF	N/A

✓	Correlation of data
(✓)	Correlation when knowledge of historical asset management / performance considered
×	No correlation of data but justified
N/A	Insufficient data to allow correlation to be observed or not applicable to the asset class

The correlation between the results of the HROF model and the history of notifications and asset replacements indicates that the HROF Model produces a metric that is appropriate for assessing the increasing risk to the network posed by this asset type.

7.4 Overhead Conductor

7.4.1. Background Data

The overhead conductor asset class includes all LV, HV and Sub-transmission conductors, open wire and ABC conductors. Replacement of overhead conductor is driven by notifications and is almost purely reactive in this regard. With comparison to other asset classes the quantity of replacement in this class is reasonably low.

7.4.2. Validation Analytics

Figure 33 shows the notifications against assets at HROF for overhead conductor. The lead indication associated with low to high priority notifications is not observed. This is due to the ability to accurately assess damage/condition from visual inspection. Typically damage or poor condition assessments of conductor result in a higher priority notification immediately, without necessarily being identified as a lower priority initially. In, or around, 2009 the inspection process was refined in line with the expected increase in risk to the business due to aging conductor; therefore, the priority structure changed at this time and it is not possible to derive any information from the prior years.

It is expected that the replacements, shown in Figure 34, will remain relatively flat over the coming period. The expenditure is increasing due to the increased unit rate for replacement, due to the replacement of HV ABC which has a much higher unit rate than bare overhead conductor.

Figure 33: Notifications vs. Assets at HROF – Conductors

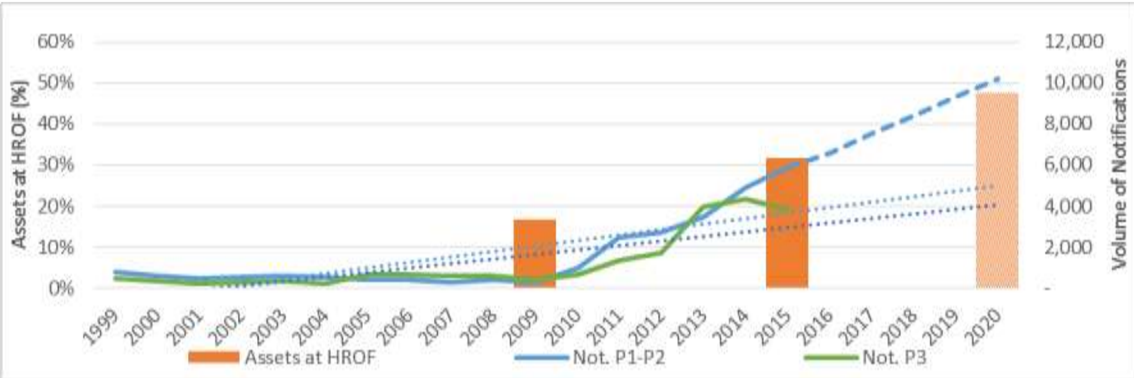


Figure 34: Replacement vs. Assets at HROF – Conductors

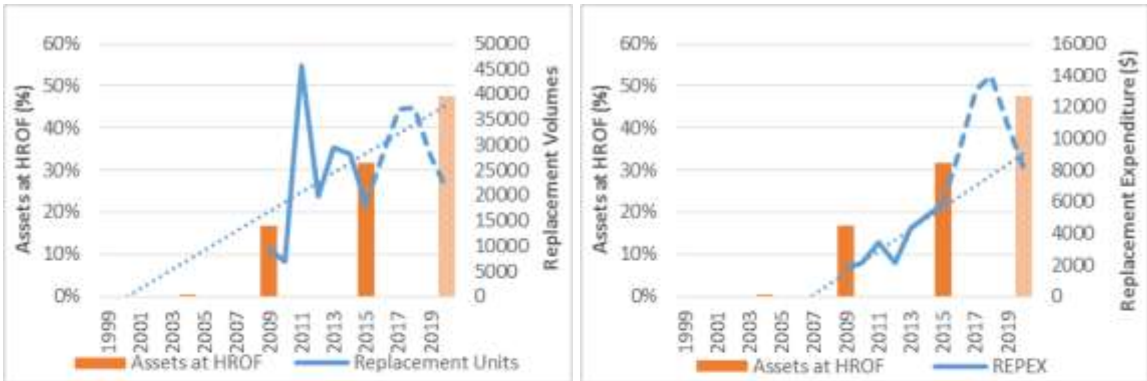
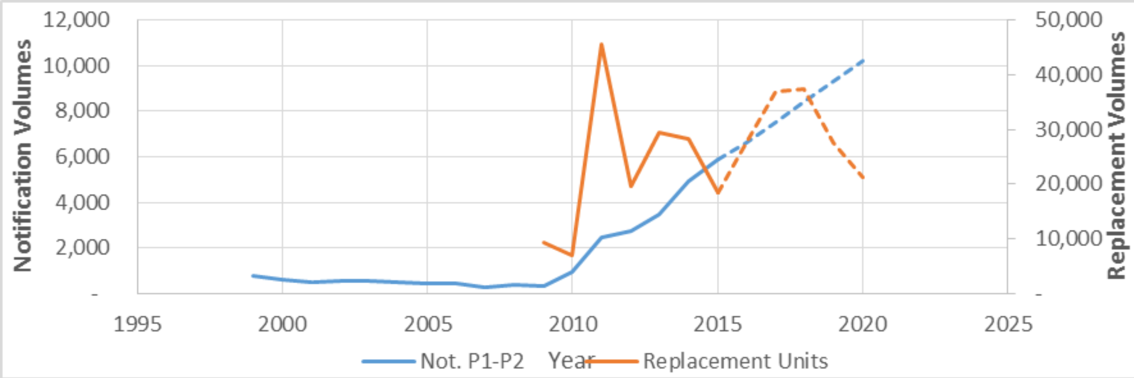


Figure 35: High Priority Notifications vs. Replacement – Conductors



This asset class demonstrates a good correlation between SAIFI and outages and assets at HROF (Figure 35). It is expected that the SAIDI and SAIFI will continue to increase in line with the assets at HROF. This is due to the difficulty with efficient strategic targeting of conductor which is about to fail. Outside HBRA there is relatively low risk due to failure of overhead conductor, therefore it is typically replaced reactively at failure.

Figure 36: SAIFI / Outages vs. Assets at HROF – Conductors

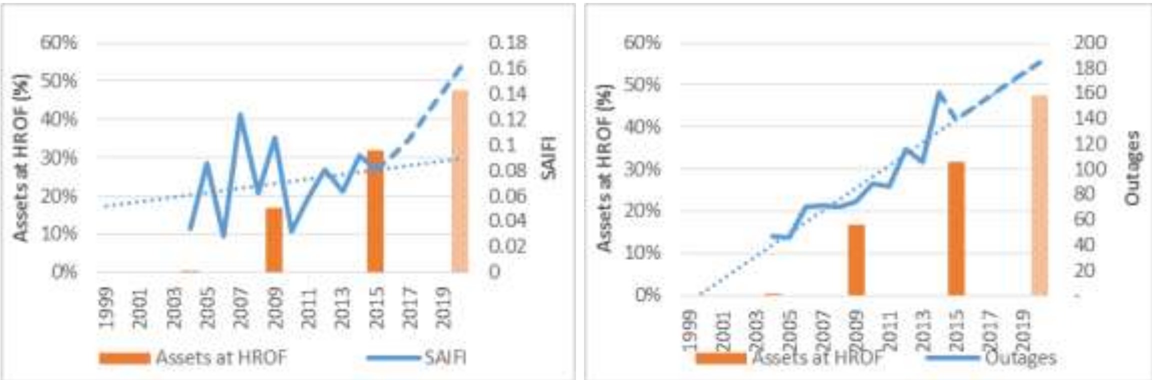


Table 20: Validation Analysis Summary - Conductors

Validation Test	Correlation
Notifications vs. Assets at HROF	✓
Replacement (Vol) vs. Assets at HROF	(✓)
Replacement ($) vs. Assets at HROF	✓
High Priority Notifications vs. Replacement (Vol)	(✓)
SAIFI vs. Assets at HROF	✓
Outages vs. Assets at HROF	✓

✓	Correlation of data
(✓)	Correlation when knowledge of historical asset management / performance considered
×	No correlation of data but justified
N/A	Insufficient data to allow correlation to be observed or not applicable to the asset class

The correlation between the results of the HROF model and the history of notifications and asset replacements indicates that the HROF Model produces a metric that is appropriate for assessing the increasing risk to the network posed by the conductor asset type.

7.5 Underground Cable

7.5.1. Background Data

The Underground Cable asset class includes all LV, HV and sub-transmission cable, both XLPE and NON-XLPE. Also included in this asset class are LV pillars, pits and cabinets and HV surge arrestors. HV and LV cables follow a run to failure regime with condition assessment as part of repair. Cable is replaced based on fault history, frequency of failure and condition assessment. Pits and pillars are inspected regularly and repaired or replaced based on condition. There is a safety program underway to replace Doncaster pillars.

7.5.2. Validation Analytics

Figure 37: Notifications vs. Assets at HROF – Underground Cable

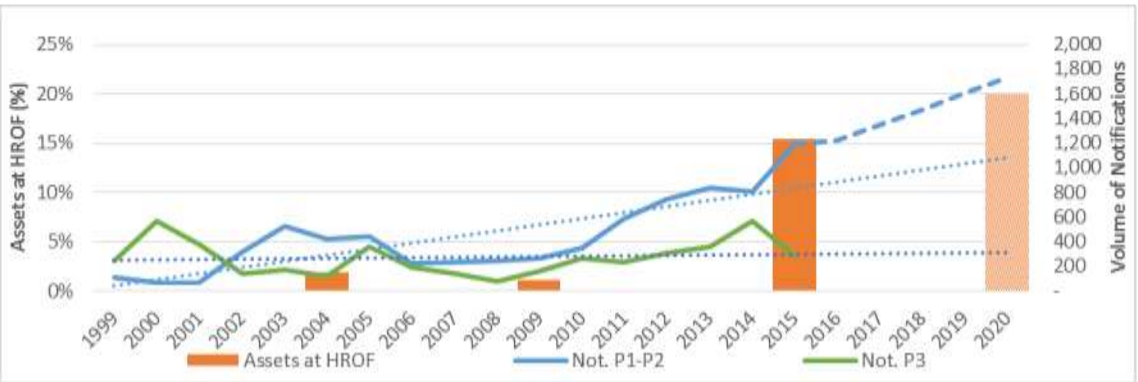
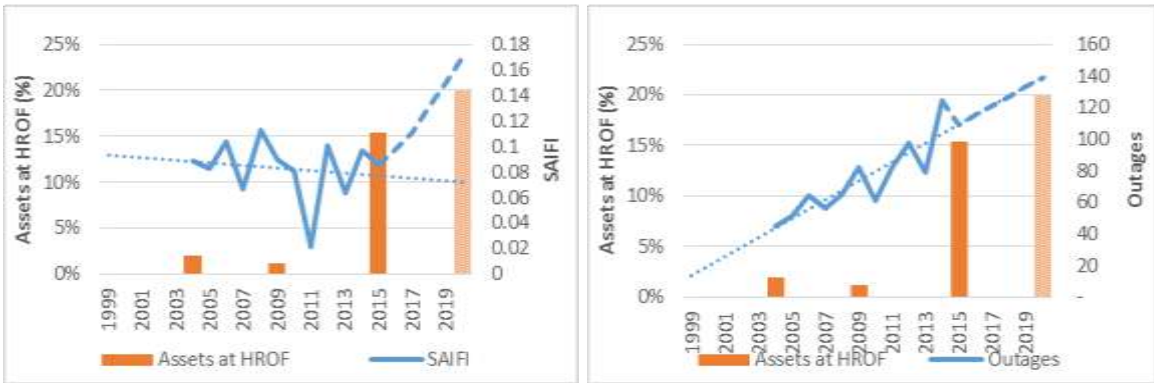


Figure 38: Replacement vs. Assets at HROF – Underground Cable

Figure 39: High Priority Notifications vs. Replacement – Underground Cable

Figure 40: SAIFI / Outages Vs. Assets at HROF – Underground Cable



This category covers a broad range of asset types, with very different inspection regimes and replacement costs. Figure 37 shows that the number of notifications correlates with the percentage of assets at HROF. P3 notifications are not a good lead indicator in this asset class due to the limited inspection that can be undertaken. The P3 notifications largely relate to the LV Doncaster pillars and have decreased in 2015 as a result of the dedicated replacement program.

Figure 39 shows the high correlation between P1 and P2 notifications and the number of asset replacements. The divergence in 2014 to 2015 is a result of the increase replacement of LV Doncaster pillars.

Figure 38 shows an apparent inconsistency between replacement units and repex costs. There are two drivers that resulted in these profiles. Firstly, there was a change in contractual arrangements in around 2011 that resulted in changed target rates that improved efficiency. Secondly, an increase in replacement of feeder exit cables and other zone substation cables resulted in a lower cost per unit length. The lower cost was due to no requirement for reinstatement of public land, need for traffic control or other peripheral costs. The Repex then start to increase in line with the increasing replacement units.

Underground cables are managed as run to failure assets and their impact on the network varies according to their location and voltage level.

Figure 40 shows the number of outages correlates strongly with the HROF and indicates that HROF is a suitable metric for considering the condition of these assets. However, the correlation between SAIFI and HROF is less pronounced. The reason is that SAIFI is weighted by the number of customers affected by each outage. Therefore, if there is an outage of a HV cable there is likely to be a large contribution to SAIFI, or a load transfer to prevent the outage, but an outage of an LV cable is likely to have a much smaller impact.

The basis for the forecast for SAIFI shown in Figure 40 is on the assumption that the proposed reliability maintenance strategy expenditure included in UE's submission is approved by the AER. If the proposal is modified, then the forecast reliability will deteriorate.

Table 21: Validation Analysis Summary - Underground Cable

Validation Test	Correlation
Notifications vs. Assets at HROF	✓
Replacement (Vol) vs. Assets at HROF	✓
Replacement ($) vs. Assets at HROF	✗
High Priority Notifications vs. Replacement (Vol)	✓
SAIFI vs. Assets at HROF	✗
Outages vs. Assets at HROF	✓

✓ Correlation of data
(✓) Correlation when knowledge of historical asset management / performance considered
✗ No correlation of data but justified
N/A Insufficient data to allow correlation to be observed or not applicable to the asset class

As demonstrated in this section, the number of outages and the trend of notifications correlates well with the number of underground assets at HROF and therefore support HROF as a suitable metric that is appropriate for assessing the increasing risk to the network posed by this asset type.

7.6 Distribution Switchgear

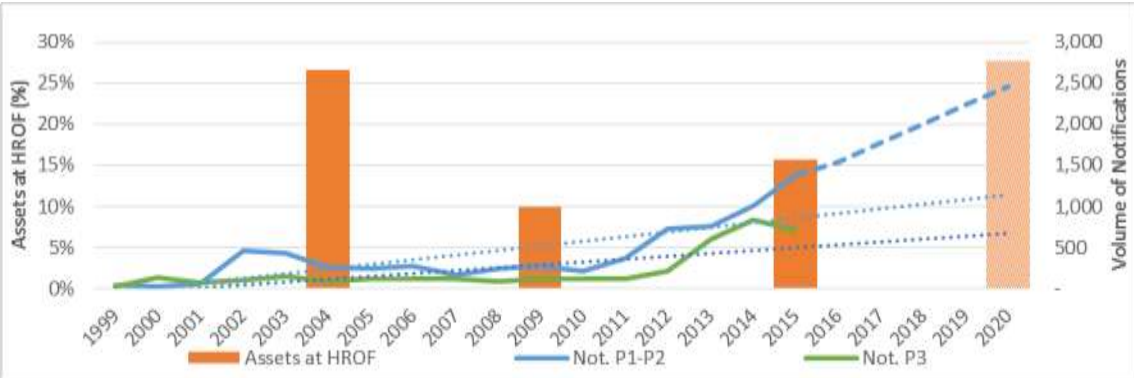
7.6.1. Background Data

Distribution switchgear includes all switches outside of a zone substation. There are different types of switches for different voltage levels that all impact the network performance differently and have different replacement values. Therefore, the value of HROF assets is dependent on the type of switch as well as the number of switches that have passed the HROF threshold.

The asset types and total value of this asset category have changed significantly since 2004. Since 2005 there has been a focus on installing three new asset types of ACRs, RCGS and HV Line Capacitors. These items are more expensive and have resulted in increasing the total value of the asset category. As a result, even though the total value of assets at HROF has increased, the percentage of the assets has decreased due to the high value of new assets. This distorts the charts in this section which show HROF as a percentage of the asset base.

7.6.2. Validation Analytics

Figure 41: Notifications vs. Assets at HROF – DSS Switchgear



Distribution switchgear is managed as both run to failure and as a managed asset depending on several factors including the criticality of its location on the network, the voltage level and the type of switch.

Figure 41 shows the relationship between assets at HROF as a percentage of the asset category value and the number of notifications. Due to the significantly changed value of the asset category as a result of different asset types being installed, the data from 2004 should be ignored for the purpose of this analysis in this asset category as it is not providing a ‘like for like’ comparison.

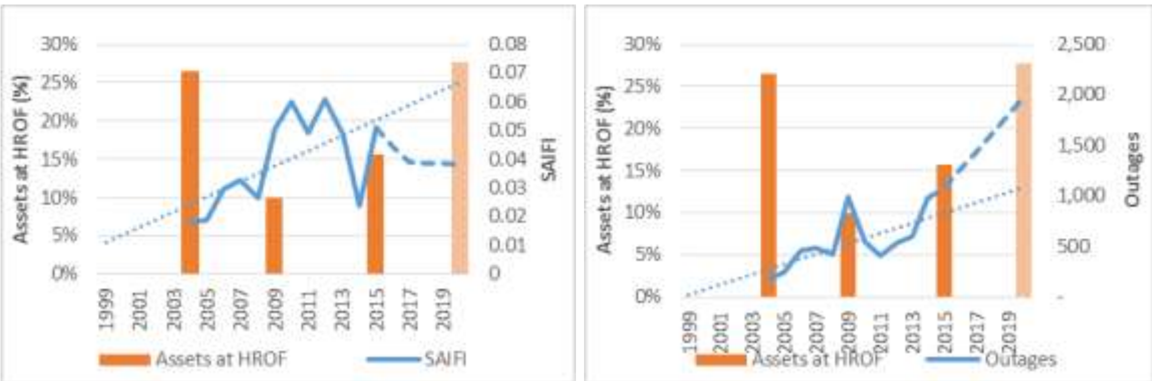
Considering 2009 to 2020 shows a strong correlation between notifications and HROF.

Figure 42 shows a spike in the replacement volumes in 2014 which was due to a dedicated replacement program targeting unsafe HV switches. The forward repex forecast is higher as a result of increased number of RCGS or ACRs being installed when replacing manual switches. The current standard replacement item is either a remote controlled gas switches or ACR which have a higher unit cost than the manual gas switches. Therefore, the repex value has increased while the replacement units have reduced to approximately 100 per year.

Figure 42: Replacement vs. Assets at HROF – DSS Switchgear

Figure 43: High Priority Notifications vs. Replacement – DSS Switchgear

Figure 44: SAIFI / Outages vs. Assets at HROF – DSS Switchgear



Switch failures can result in outages to customers. However, the impact of an outage can vary greatly depending on whether load auto change over schemes are enabled, the location of the switch on the network and the voltage level of the switch.

Figure 44 and Figure 45 show the number of outages and SAIFI caused by switches. The number of outages correlates strongly with the HROF and indicates that HROF is a suitable metric for considering the condition of assets. However, the correlation between SAIFI and HROF is less pronounced. Since SAIFI is weighted by the number of people affected, an outage of a HV switch is likely to have a large contribution to SAIFI, whereas an outage of an LV switch is likely to have a much smaller impact. Therefore, the number of outages correlates with HROF and supports it as a suitable metric for this asset class.

The basis for the forecast for SAIFI shown in Figure 44 is on the assumption that the proposed reliability maintenance strategy expenditure included in UE's submission is approved by the AER. If the proposal is modified, then the forecast reliability will worsen.

Table 22: Validation Analysis Summary - DSS Switchgear

Validation Test	Correlation
Notifications vs. Assets at HROF	(✓)
Replacement (Vol) vs. Assets at HROF	(✓)
Replacement ($) vs. Assets at HROF	✓
High Priority Notifications vs. Replacement (Vol)	(✓)
SAIFI vs. Assets at HROF	(✓)
Outages vs. Assets at HROF	✓

✓	Correlation of data
(✓)	Correlation when knowledge of historical asset management / performance considered
×	No correlation of data but justified
N/A	Insufficient data to allow correlation to be observed or not applicable to the asset class

As demonstrated in this section, distribution switchgear cables exhibit a good relationship to HROF and therefore support HROF as a suitable metric that is appropriate for assessing the increasing risk to the network posed by this asset type.

7.7 Distribution Transformers

7.7.1. Background Data

Distribution transformers include all transformers outside of a zone substation. Transformers can have differing impact on network performance based on their capacity as larger transformers will typically supply more customers. Additionally, larger transformers are more expensive so the value of HROF assets is dependent on the capacity of the transformers as well as the number of transformers that have passed the HROF threshold.

Transformers are heavily affected by temperature as heat damages the insulation and accelerates deterioration. As a result, periods of heavy loading during periods of high ambient temperatures, such as hot summer days, are detrimental to transformers and decrease their expected life.

7.7.2. Validation Analytics

Figure 45: Notifications vs. Assets at HROF – DSS Transformers

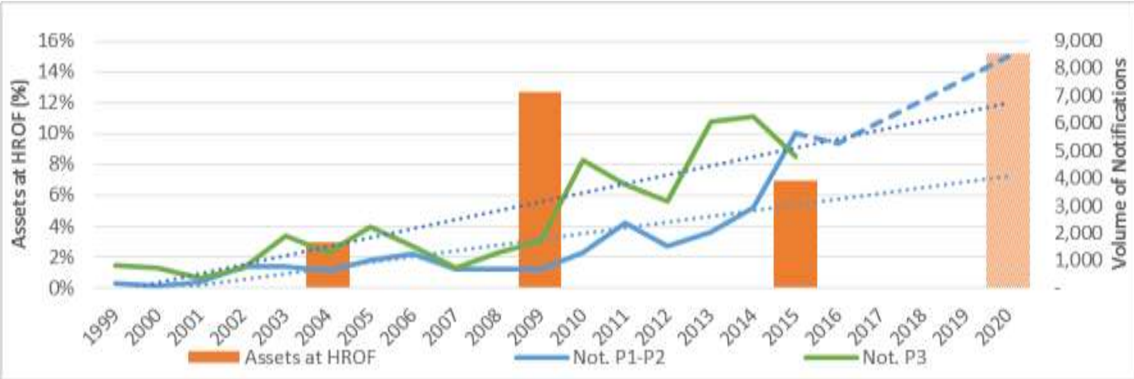
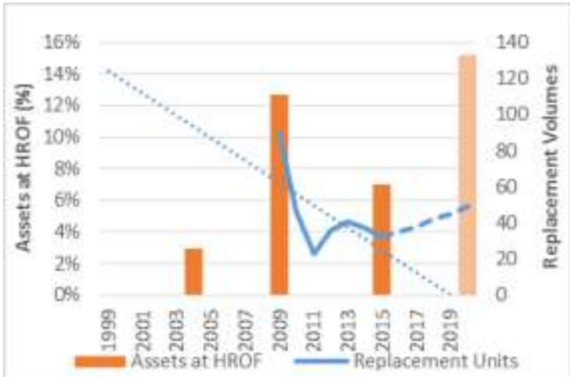


Figure 46: Replacement vs. Assets at HROF – DSS Transformers



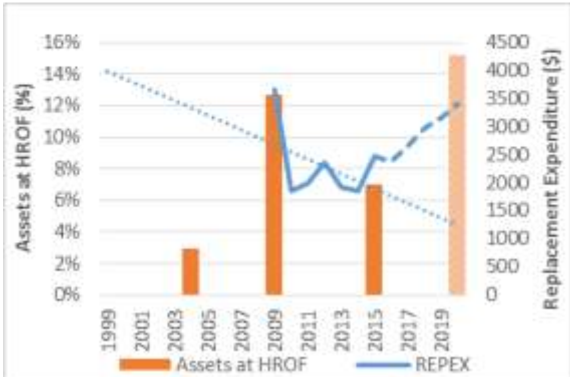


Figure 46 shows there was a large number of replacements in 2009. This was a result of two main causes: firstly, a replacement programme for distribution transformers that did not have sufficient clearance from the ground to meet modern standards; and secondly, the heat wave in January 2009 which resulted large scale failure of the transformers due to thermal overload. The number of assets at HROF subsequently decreased in 2015. Despite this, forecasting on the same basis and using conservative replacement assumptions in the model, the percentage of HROF assets is forecast to increase during the next 5 years. This is supported by the age profile shown in section 6.5 and the trend of the notifications.

This analysis also identified the strong relationship between notification categories. Figure 45 shows there is a time delay of approximately two years between the profile of P3 notifications and the profile of P1 and P2 notifications. This shows P3s to be a lead indicator for P1 and P2 level notifications and the need to replace distribution transformers.

The number of outages and SAIFI shown in Figure 48 have both decreased in line with the reduction in the number of assets at HROF. This aligns with the large number of replacements undertaken in 2009. However, it is important to note that the replacement of transformers due to height is now only undertaken at the time of replacement as only low priority transformers remain, and there have not been any severe weather events that could trigger mass failure like the 2009 heat wave. As a result, the SAIFI and outage metric is not as important for this asset class.

Figure 47: High Priority Notifications vs. Replacement – DSS Transformers

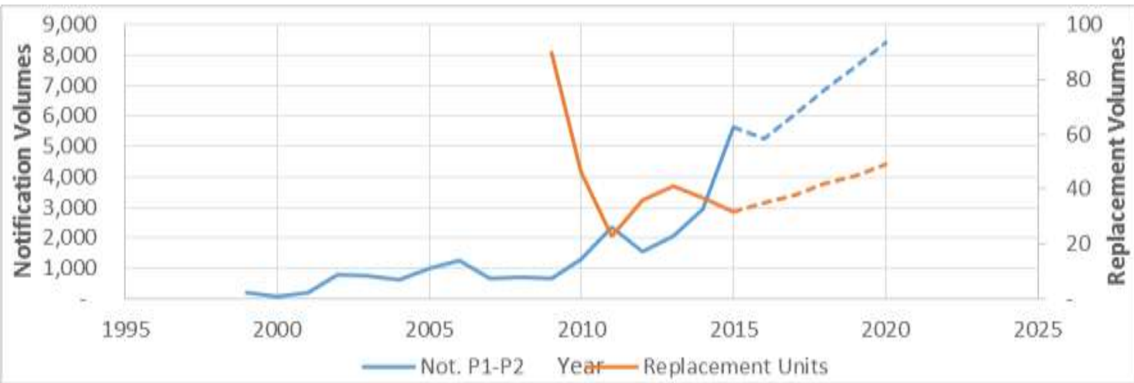


Figure 48: SAIFI / Outages vs. Assets at HROF – DSS Transformers

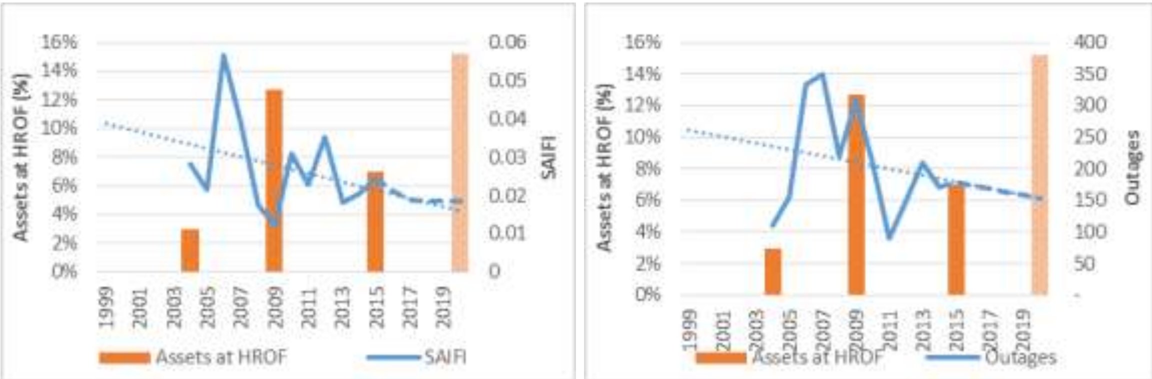


Table 23: Validation Analysis Summary - DSS Transformers

Validation Test	Correlation
Notifications vs. Assets at HROF	(✓)
Replacement (Vol) vs. Assets at HROF	✓
Replacement ($) vs. Assets at HROF	✓
High Priority Notifications vs. Replacement (Vol)	(✓)
SAIFI vs. Assets at HROF	N/A
Outages vs. Assets at HROF	N/A

✓	Correlation of data
(✓)	Correlation when knowledge of historical asset management / performance considered
×	No correlation of data but justified
N/A	Insufficient data to allow correlation to be observed or not applicable to the asset class

As demonstrated in this section, distribution transformers exhibit a good relationship to HROF and therefore support HROF as a suitable metric that is appropriate for assessing the increasing risk to the network posed by this asset type.

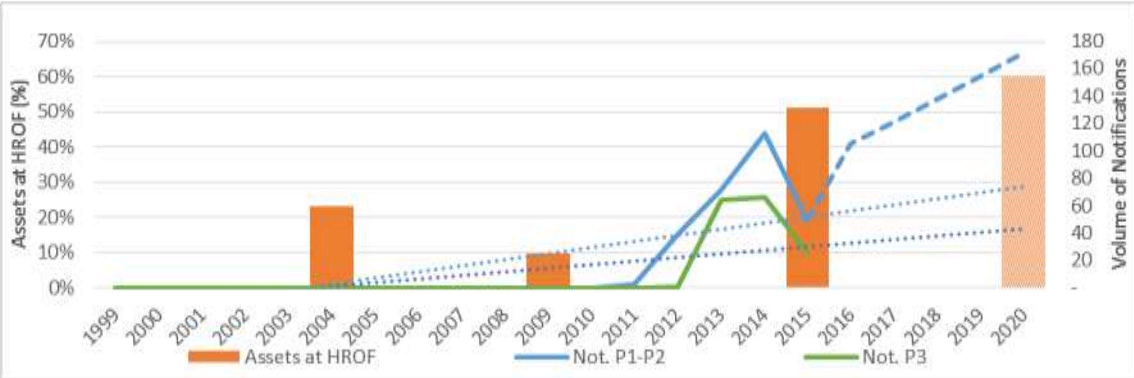
7.8 Zone Substation Switchgear

7.8.1. Background Data

Zone substation switchgear replacement is not typically driven by notifications, but instead by condition assessment of the assets themselves. Certain components of zone substation switchgear can be replaced singularly, however, the majority of the installed asset base is located on indoor switchboards which must be replaced in full. This can limit the ability to make small changes to the replacement volumes, as one project often involves many units.

7.8.2. Validation Analytics

Figure 49: Notifications vs. Assets at HROF – ZSS Switchgear



Although SAP was only configured to record notifications for this asset category from 2011, the current trend indicates that the number of notifications correlates to the assets at HROF. The trend is forecast to continue as the aging asset base progresses through the wear-out phase. The forecast increase in the number of assets entering the wear out phase is shown in the age profile in section 6.6.

Zone substation switchgear is a carefully managed asset that is replaced prior to failure. Therefore, the assets at HROF are not expected to have a close correlation to the number of failures but is expected to have a relationship with asset replacements. The relationship between these indicators is not strong due to:

- switchgear typically being replaced as a full switchboard rather than individual circuit breakers
- timing of switchboard replacement can be delayed to align to other works
- maintenance/replacement of parts is possible and can improve asset condition.

Figure 50 shows that there has been an increase in replacement in 2013 and 2014 as HROF has increased. The replacements are expected to increase during the next regulatory period.

The number of customer outages and SAIFI caused by zone substation switchgear is typically very low as there is redundancy built into the network design to ensure customers can remain on supply. Therefore SAIFI is not expected to have close correlation to assets at HROF.

Figure 50: Replacement vs. Assets at HROF – ZSS Switchgear

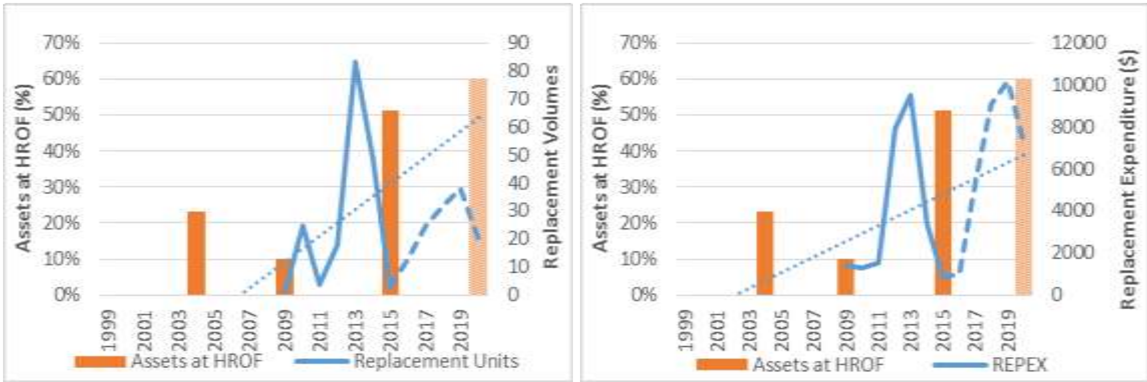


Figure 51: High Priority Notifications vs. Replacement – ZSS Switchgear

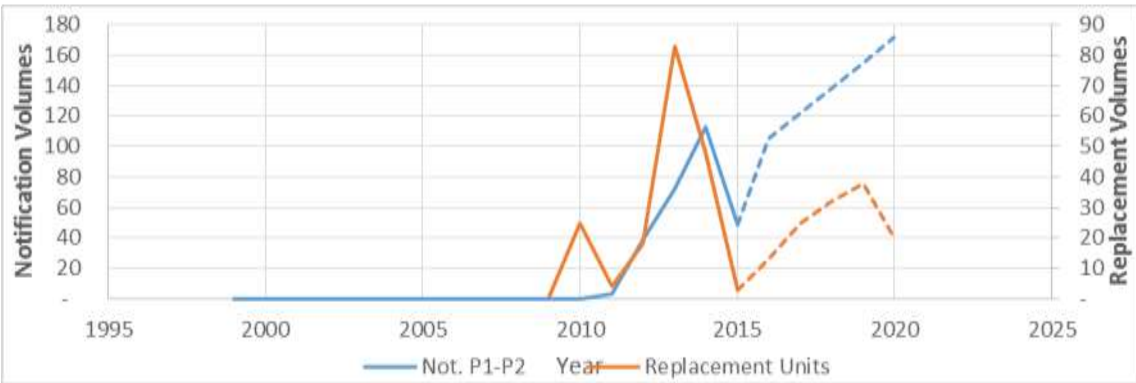


Figure 52: SAIFI / Outages vs. Assets at HROF – ZSS Switchgear

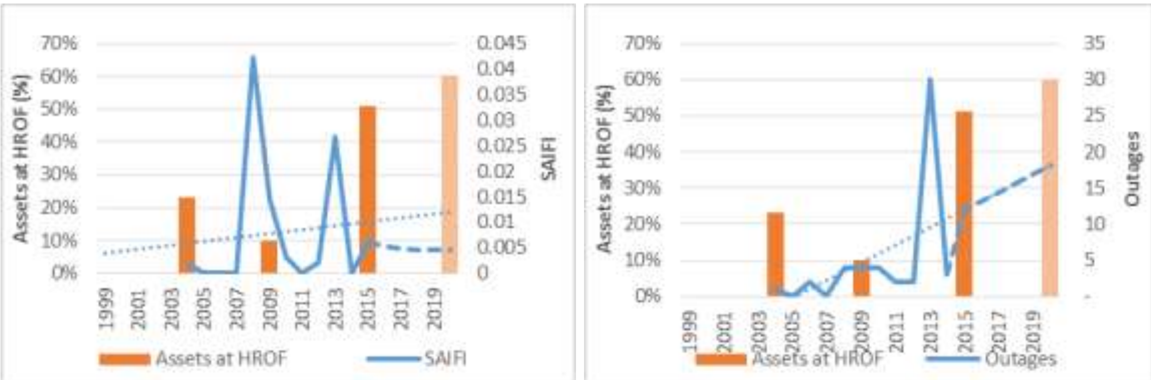


Table 24: Validation Analysis Summary – ZSS Switchgear

Validation Test	Correlation
Notifications vs. Assets at HROF	(✓)
Replacement (Vol) vs. Assets at HROF	(✓)
Replacement ($) vs. Assets at HROF	(✓)
High Priority Notifications vs. Replacement (Vol)	(✓)
SAIFI vs. Assets at HROF	N/A
Outages vs. Assets at HROF	N/A

✓	Correlation of data
(✓)	Correlation when knowledge of historical asset management / performance considered
×	No correlation of data but justified
N/A	Insufficient data to allow correlation to be observed or not applicable to the asset class

Although the relationship between HROF and ZSS Switchgear is not as strong as for other asset classes, HROF is still considered a suitable metric to use for a high level, top down view to measure risk this asset category.

7.9 Zone Substation Transformers

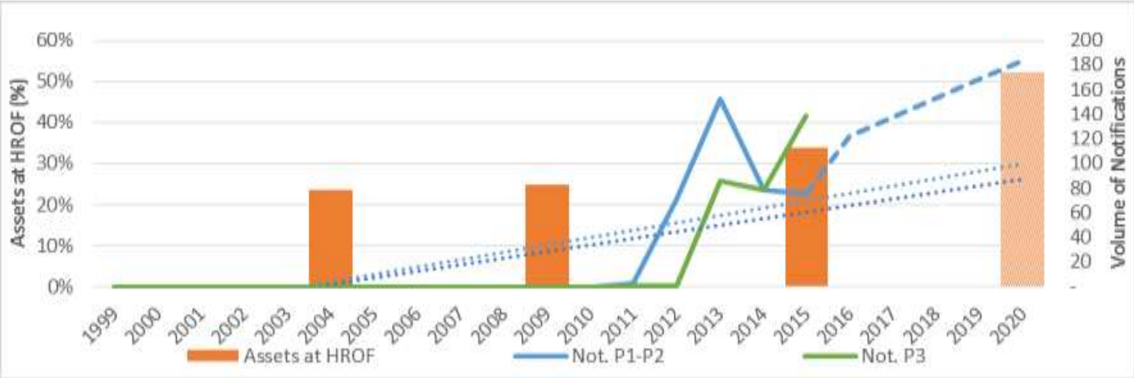
7.9.1. Background Data

The zone substation transformers category includes all transformers located within a substation. These assets are highly critical and are therefore carefully managed to avoid failure. Significant condition assessments are carried out to determine the need to replace individual assets and redundancy is built into the network to prevent an outage from affecting customers.

United Energy has recently experienced a transformer failure which highlights the increased risk which is present due to the large number of assets that are currently either approaching or exceeding their design life.

7.9.2. Validation Analytics

Figure 53: Notifications vs. Assets at HROF – ZSS Transformers



Although SAP was only configured to recorded notifications for this asset category from 2011, the current trend indicates that the number of notifications correlates to the assets at HROF. The trend is forecast to continue as the aging asset base progresses through the wear-out phase. The forecast increase in the number of assets entering the wear out phase is shown in the age profile in Section 6.7.

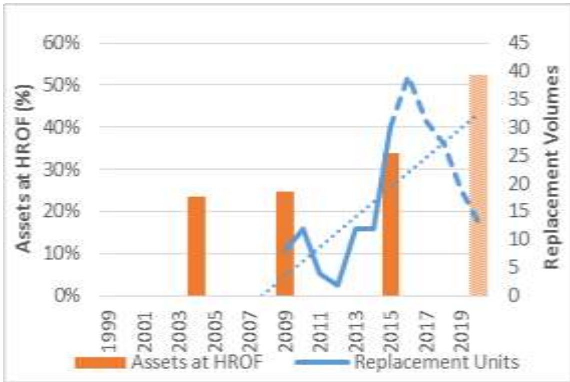
Zone substation transformers are a carefully managed asset class that is replaced prior to failure. Therefore, the assets at HROF are not expected to have a close correlation to the number of failures but is expected to have a relationship with asset replacements. The relationship between these indicators is not strong due to:

- Transformers are high value assets and managed to remain in service as long as possible
- maintenance/replacement of parts, treatment of insulating oil or full refurbishment are undertaken where efficient and can improve asset condition therefore extending their serviceable life
- timing of transformer replacement can be delayed to align to other works
- other solutions can be implemented such as retaining the transformer as a ‘hot stand-by’ rather than decommissioning when a new transformer is installed

Figure 54 shows that there has been an increase in replacement in 2013 to 2015 as HROF has increased. The replacements are expected to increase during the next regulatory period.

The number of customer outages and SAIFI due to zone substation transformer is typically very low as there is redundancy built into the network design to ensure customers can remain on supply. Therefore SAIFI and outages are not expected to have close correlation to assets at HROF.

Figure 54: Replacement vs. Assets at HROF – ZSS Transformers



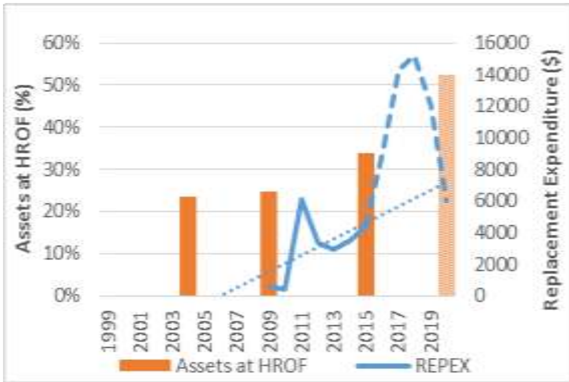


Figure 55: High Priority Notifications vs. Replacement – ZSS Transformers

Figure 56: SAIFI / Outages vs. Assets at HROF – ZSS Transformers

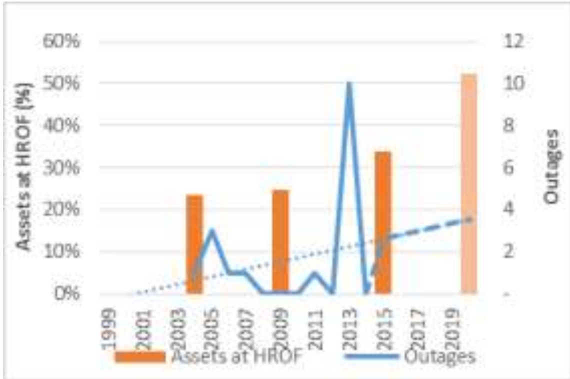


Table 25: Validation Analysis Summary – ZSS Transformers

Validation Test	Correlation
Notifications vs. Assets at HROF	(✓)
Replacement (Vol) vs. Assets at HROF	✓
Replacement ($) vs. Assets at HROF	(✓)
High Priority Notifications vs. Replacement (Vol)	(✓)
SAIFI vs. Assets at HROF	N/A
Outages vs. Assets at HROF	N/A

✓	Correlation of data
(✓)	Correlation when knowledge of historical asset management / performance considered
×	No correlation of data but justified
N/A	Insufficient data to allow correlation to be observed or not applicable to the asset class

Although the relationship between HROF and ZSS Transformers is not as strong as for other asset classes, HROF is still considered a suitable metric to use for a high level, top down view to measure risk this asset category.

7.10 Services

7.10.1. Background Data

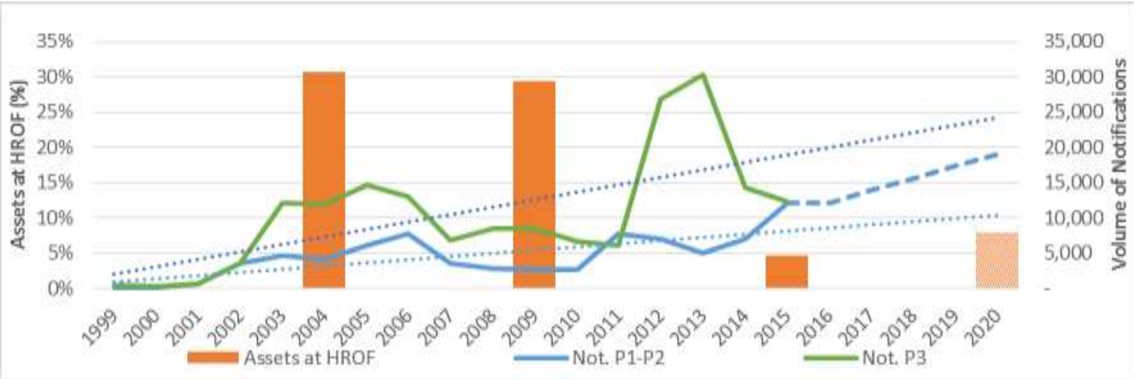
The services asset category covers all connections from the electricity network to private property including residential, commercial and industrial customers.

Replacement of services is driven primarily by notifications, with priority one and two notifications typically resulting in a replacement of the related asset within 90 days or 180 days, respectively. This asset class has the highest volumes as there is typically one service per customer. The failure of a service typically has a very low impact to overall network reliability and are only replaced proactively in response to a safety concern.

Services have undergone a large program of replacement driven by safety concerns for a specific type of service. Therefore, this asset class has seen a large decrease in the volume of assets at HROF since 2009.

7.10.2. Validation Analytics

Figure 57: Notifications vs. Assets at HROF - Services



As shown in Figure 57, there is not a strong correlation between the number assets at HROF and notifications. This particular asset class has been subject to a significant targeted replacement program in the last regulatory period for neutral screened cables. This replacement program was carried out for safety reasons rather than age related risk. During the replacement program, notifications were raised when the neutral screened cables were located to drive the replacements. The number of notifications is therefore distorted by these replacements that are not driven by aging assets.

The targeted replacements have had the result of decreasing the assets at HROF due to the large volume of assets replaced. As a result, the forecast volume of services forecast to be replaced during the next period will be significantly lower. This is shown in Figure 58. The number of outages and asset failures has decreased and the decreased trend is forecast to continue during the next regulatory period, as shown in Figure 60. The SAIFI impact of services is negligible as typically only one customer is affected by each service failure. Therefore, this does not provide a useful relationship for this asset class.

Figure 58: Replacement vs. Assets at HROF - Services

Figure 59: High Priority Notifications vs. Replacement - Services

Figure 60: SAIFI/SAIDI vs. Assets at HROF - Services

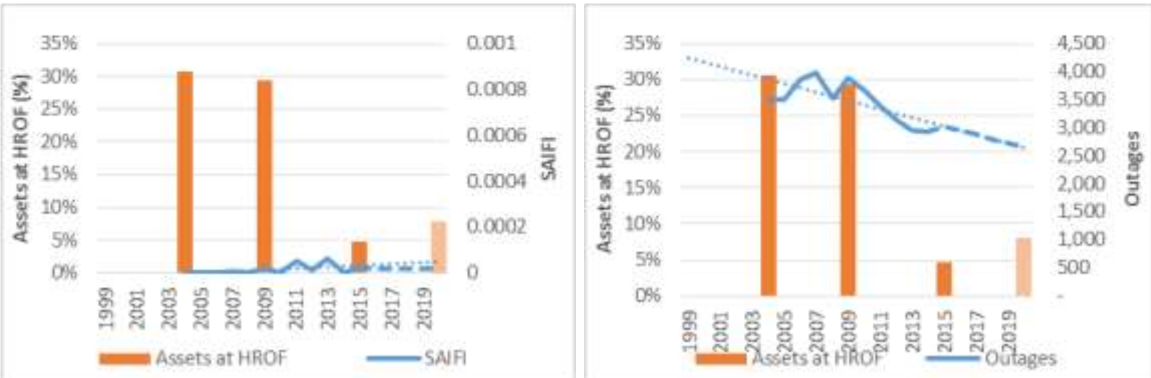


Table 26: Validation Analysis Summary - Services

Validation Test	Correlation
Notifications vs. Assets at HROF	×
Replacement (Vol) vs. Assets at HROF	×
Replacement ($) vs. Assets at HROF	×
High Priority Notifications vs. Replacement (Vol)	×
SAIFI vs. Assets at HROF	N/A
Outages vs. Assets at HROF	✓

✓	Correlation of data
(✓)	Correlation when knowledge of historical asset management / performance considered
×	No correlation of data but justified
N/A	Insufficient data to allow correlation to be observed or not applicable to the asset class

Due to the distortion of notifications caused by the targeted replacement program it is not possible to clearly establish whether assets at HROF has been a good indicator of risk on the network due to this distortion of data. However, it is expected that assets at HROF and notifications will show a clearer relationship over the coming years.

7.11 Validation Summary

Table 27 sets out the summary of the validation analysis carried out for each asset. In general, the validation has shown relationships in the data that supports the HROF metric as being a suitable indicator for increases / decreases in asset replacements and expenditure. This validation has often needed to consider knowledge of the particular asset class to understand where notifications, or replacements have not been typical, or when there has been changes in the way asset performance information has been captured. The only asset class that has not demonstrated a clear trend is services, which is due to the distortion of data caused by a significant targeted replacement program.

With the majority of asset classes being managed by proactive replacement, where assets are replaced on condition and prior to failure, the volume of assets reaching failure is not high enough to show trends in SAIFI and outages against assets at HROF for most asset classes

It can be concluded that in general it was found that the HROF metric correlates with the key performance indicators for the most asset classes.

Table 27: Validation Summary Table

Validation Test	Poles	Overhead Conductor	Underground Cables	Dist. Switchgear	Dist. Transformer	ZSS Switchgear	ZSS Transformer	Services	OVERALL NETWORK	Comments
Notifications vs. Assets at HROF	(✓)	✓	✓	(✓)	(✓)	(✓)	(✓)	×	✓	
Replacement (Vol) vs. Assets at HROF	(✓)	(✓)	✓	(✓)	✓	(✓)	✓	×	✓	
Replacement ($) vs. Assets at HROF	(✓)	✓	×	✓	✓	(✓)	(✓)	×	✓	
High Priority Notifications vs. Replacement (Vol)	✓	(✓)	✓	(✓)	(✓)	(✓)	(✓)	×	(✓)	
SAIFI vs. Assets at HROF	N/A	✓	×	(✓)	N/A	N/A	N/A	N/A	✓	
Outages vs. Assets at HROF	N/A	✓	✓	✓	N/A	N/A	N/A	✓	×	

✓ Correlation of data
(✓) Correlation when knowledge of historical asset management / performance considered
× No Correlation of data but justified
N/A Insufficient data to allow correlation to be observed or not applicable to the asset class

8. Conclusion

United Energy has an aging asset population, with a large portion of assets that are now approaching their expected / design life. Due to the implications of large quantities of aging assets on required replacement, reliability and safety, United Energy has established a model to measure the number of assets that are at higher risk of failure (HROF). Assessing assets at HROF can be used to ascertain whether the network health is being maintained and whether specific asset strategies are reasonable.

The Assets at HROF model can be relied upon as a robust indicator of network health since

- It is soundly based on assets at the end of the life cycle that are entering the wear out phase.
- It is built on readily available data submitted to the AER, is thus transparent.
- It has been verified by checking inputs and calculations for errors, and confirming it is not sensitive to variations in inputs like asset lives and unit rates, or the age threshold selected.
- It has been validated against historical network performance.

The model is therefore suitable for use in a top down assessment of the total Repex needed to maintain reliability and network safety.

The Asset at HROF model indicates that the underlying health of the network will continue to deteriorate, essentially due to aging assets, supporting the need for more Repex in the forthcoming period than in the current period to maintain reliability and network safety, all other factors being equal.

The HROF model found that with the proposed level of asset replacement expenditure, the percentage of assets at HROF is forecast to increase between 2015 and 2020 by about 4%, equivalent to around $400m in value.

Given United Energy's commitment to ensuring prudent and efficient expenditure on the network, specific strategies have been established that allow reliability and network safety to be maintained with this increased level of risk, by striking a balance between replacements and other strategies.

9. Definitions

Term	Definition
AER	Australian Energy Regulator
CBRM	Condition Based Risk Management
DSS	Distribution Substations Switchgear
HI	Health Index
HROF	High Risk of Failure
Repex	Replacement Expenditure
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
ZSS	Zone Substation

10. References

1. **United Energy.** *Network Reliability Assessment.* 2015.

2. —. *Safety Assessment Report.* 2015.

3. **EA Technology.** *Application of CBRM with United Energy Report.* J000158-1.

Appendix A: Asset Categories

ASSET CATEGORY	BREAKDOWN
Poles	- All Low Voltage, High Voltage and Sub-transmission - Wood, Concrete and Steel Poles - All Staked Poles
Pole Top Structures	- All Low Voltage, High Voltage and Sub-transmission - Wood and Steel Crossarms
Overhead Conductors	- All Low Voltage, High Voltage and Sub-transmission - Open wire (Bare) - ABC conductor
Underground Cables	- All Low Voltage, High Voltage and Sub-transmission - XLPE and NON-XLPE Cable - LV Pillars, Pits and Cabinets - HV Surge Arrestors
Public Lighting	- Lighting Poles for Major and Minor Roads - Lamps and Luminaires for Major and Minor Roads
Distribution Transformers	- Pole mounted - Ground mounted - Indoor Substations
Zone Substation Transformers	- Ground/Indoor >=22kV and >=33kV and <15 MVA - Ground/Indoor >33kV and >=66kV and >15MVA <40MVA - Transformer Bushings and Onload tap changer
Distribution Switchgear	- Pole mounted Fuses/Isolators and Switchers - ACRs and RCGS - Line Caps
Zone Substation Switchgear	- All 11kV, 22kV and 66kV Circuit Breakers
Service Lines	- Simple and Complex Residential services - Simple and Complex Commercial services

Appendix B: Asset Useful Lives used in HROF Model

Asset Class	Asset Category	RIN Code	Useful Life used in HROF Model
POLES	< = 1 kV; Wood	Pole-LV-W-N	69.800
	> 1 kV & < = 11 kV; Wood	Pole-11-W-N	68.400
	> 11 kV & < = 22 kV; Wood	Pole-22-W-N	68.400
	> 22 kV & < = 66 kV; Wood	Pole-66-W-N	68.400
	> 66 kV & < = 132 kV; Wood		N/A
	> 132 kV; Wood		N/A
	< = 1 kV; Concrete	Pole-LV-C-N	100.000
	> 1 kV & < = 11 kV; Concrete	Pole-11-C-N	100.000
	> 11 kV & < = 22 kV; Concrete	Pole-22-C-N	100.000
	> 22 kV & < = 66 kV; Concrete	Pole-66-C-N	100.000
	> 66 kV & < = 132 kV; Concrete		N/A
	> 132 kV; Concrete		N/A
	< = 1 kV; Steel	Pole-LV-S-N	100.000
	> 1 kV & < = 11 kV; Steel	Pole-11-S-N	100.000
	> 11 kV & < = 22 kV; Steel	Pole-22-S-N	100.000
	> 22 kV & < = 66 kV; Steel	Pole-66-S-N	47.200
	> 66 kV & < = 132 kV; Steel		N/A
	> 132 kV; Steel		N/A
	STAKED < = 1 kV; Wood	Pole-LV-W-S	24.400
	STAKED > 1 kV & < = 11 kV; Wood	Pole-11-W-S	24.400
	STAKED > 11 kV & < = 22 kV; Wood	Pole-22-W-S	24.400
	STAKED > 22 kV & < = 66 kV; Wood	Pole-66-W-S	24.400
	Other		0.000
POLE TOP STRUCTURES	< = 1 kV	PTOP-LV	48.800
	> 1 kV & < = 11 kV	PTOP-11	47.900
	> 11 kV & < = 22 kV	PTOP-22	47.900
	> 22 kV & < = 66 kV	PTOP-66	50.400
	> 66 kV & < = 132 kV		N/A
	> 132 kV		N/A
	Other		N/A
OVERHEAD CONDUCTORS	< = 1 kV		50.000
	> 1 kV & < = 11 kV		60.000
	> 11 kV & < = 22 kV ; SWER	OH-22-Bare-SWER	60.000
	> 11 kV & < = 22 kV ; Single-Phase	OH-22-Bare-SP	60.000
	> 11 kV & < = 22 kV ; Multiple-Phase		60.000
	> 22 kV & < = 66 kV	OH-66-Bare-MP	60.000
	> 66 kV & < = 132 kV		N/A
	> 132 kV		N/A

Asset Class	Asset Category	RIN Code	Useful Life used in HROF Model
	< = 1 kV ; ABC	OH-LV-ABC	50.000
	< = 1 kV ; BARE	OH-LV-Bare	60.000
	> 1 kV & < = 11 kV ; ABC	OH-11-ABC-MP	35.000
	> 1 kV & < = 11 kV ; BARE; SINGLE PHASE	OH-11-Bare-SP	60.000
	> 1 kV & < = 11 kV ; BARE; MULTIPHASE	OH-11-Bare-MP	60.000
	> 11 kV & < ≈ 22 kV ; COVERED / ABC	OH-22-ABC-MP	35.000
	> 11 kV & < ≈ 22 kV ; BARE; MUTLIPHASE	OH-22-Bare-MP	60.000
	Other		0.000
UNDERGROUND CABLES	< = 1 kV	LVUG-MAI-XLP	62.000
	> 1 kV & < = 11 kV	HVUG-11*	36.900
	> 11 kV & < = 22 kV	HVUG-22*	36.900
	> 22 kV & < = 33 kV		N/A
	> 33 kV & < = 66 kV	HVUG-66-XLP	36.900
	> 66 kV & < = 132 kV		N/A
	> 132 kV		N/A
	> 1 kV & < ≈ 11 kV ; NON-XLPE		36.900
	> 1 kV & < ≈ 11 kV ; XLPE		36.900
	≈ 22 kV ; NON-XLPE		36.900
	≈ 22 kV ; XLPE		36.900
	LV SERVICE PILLARS	LVUG-Pil	40.000
	LV PARALLELING PILLARS	LVUG-Par-Pil	40.000
	LVUG-PIT Doncaster	LVUG-PIT Doncaster	21.000
	LV CABINETS	LVUG-Cabinet	21.000
	LV Pits	LVUG-PIT	40.000
	Surge Arrestor - HV	LA	36.700
	Other		N/A
SERVICE LINES	< = 11 kV ; Residential ; Simple Type	S-RESIDENTIAL	45.500
	< = 11 kV ; Commercial & Industrial ; SimpleType	S-COMMERCIAL	45.500
	< = 11 kV ; Residential ; Complex Type	C-RESIDENTIAL	45.500
	< = 11 kV ; Commercial & Industrial ; Complex Type	C-COMMERCIAL	45.500
	< = 11 kV ; Subdivision ; Complex Type		N/A
	> 11 kV & < = 22 kV ; Commercial & Industrial		N/A
	> 11 kV & < = 22 kV ; Subdivision		N/A
	> 22 kV & < = 33 kV ; Commercial & Industrial		N/A
	> 22 kV & < = 33 kV ; Subdivision		N/A
	> 33 kV & < = 66 kV ; Commercial & Industrial		N/A
	> 33 kV & < = 66 kV ; Subdivision		N/A
	> 66 kV & < = 132 kV ; Commercial & Industrial		N/A
	> 66 kV & < = 132 kV ; Subdivision		N/A

Asset Class	Asset Category	RIN Code	Useful Life used in HROF Model
	> 132 kV ; Commercial & Industrial		N/A
	> 132 kV ; Subdivision		N/A
	Other		N/A
DISTRIBUTION TRANSFORMERS	Pole Mounted ; < = 22kV ; < = 60 kVA ; Single Phase	P-22-L-S	50.000
	Pole Mounted ; < = 22kV ; > 60 kVA and < = 600 kVA ; Single Phase	P-22-M-S	50.000
	Pole Mounted ; < = 22kV ; > 600 kVA ; Single Phase		N/A
	Pole Mounted ; < = 22kV ; < = 60 kVA ; Multiple Phase	P-22-L-M	50.000
	Pole Mounted ; < = 22kV ; > 60 kVA and < = 600 kVA ; Multiple Phase		50.000
	Pole Mounted ; < = 22kV ; > 600 kVA ; Multiple Phase	P-22-H-M	50.000
	Kiosk Mounted ; < = 22kV ; < = 60 kVA ; Single Phase	K-22-L-S	45.000
	Kiosk Mounted ; < = 22kV ; > 60 kVA and < = 600 kVA ; Single Phase	K-22-M-S	45.000
	Kiosk Mounted ; < = 22kV ; > 600 kVA ; Single Phase		N/A
	Kiosk Mounted ; < = 22kV ; < = 60 kVA ; Multiple Phase	K-22-L-M	45.000
	Kiosk Mounted ; < = 22kV ; > 60 kVA and < = 600 kVA ; Multiple Phase		45.000
	Kiosk Mounted ; < = 22kV ; > 600 kVA ; Multiple Phase	K-22-H-M	45.000
	Ground Outdoor / Indoor Chamber Mounted; < 22 kV ; < = 60 kVA ; Single Phase	G-11-L-S	N/A
	Ground Outdoor / Indoor Chamber Mounted; < 22 kV ; > 60 kVA and < = 600 kVA ; Single Phase	G-11-M-S	N/A
	Ground Outdoor / Indoor Chamber Mounted; < 22 kV ; > 600 kVA ; Single Phase	G-11-H-S	55.000
	Ground Outdoor / Indoor Chamber Mounted; < 22 kV ; < = 60 kVA ; Multiple Phase	G-11-L-M	55.000
	Ground Outdoor / Indoor Chamber Mounted; < 22 kV ; > 60 kVA and < = 600 kVA ; Multiple Phase		55.000
	Ground Outdoor / Indoor Chamber Mounted; < 22 kV ; > 600 kVA ; Multiple Phase		55.000
	Ground Outdoor / Indoor Chamber Mounted; > = 22 kV & < = 33 kV ; < = 15 MVA	ZSS TX PRIM 22	62.200
	Ground Outdoor / Indoor Chamber Mounted; > = 22 kV & < = 33 kV ; > 15 MVA and < = 40 MVA		N/A
	Ground Outdoor / Indoor Chamber Mounted; > = 22 kV & < = 33 kV ; > 40 MVA		N/A
	Ground Outdoor / Indoor Chamber Mounted; > 33 kV & < = 66 kV ; < = 15 MVA		N/A
	Ground Outdoor / Indoor Chamber Mounted; > 33 kV & < = 66 kV ; > 15 MVA and < = 40 MVA	ZSS TX PRIM 66	58.200
	Ground Outdoor / Indoor Chamber Mounted; > 33 kV & < = 66 kV ; > 40 MVA		N/A
	Ground Outdoor / Indoor Chamber Mounted; > 66 kV & < = 132 kV ; < = 100 MVA		N/A
	Ground Outdoor / Indoor Chamber Mounted; > 66 kV & < = 132 kV ; > 100 MVA		N/A

Asset Class	Asset Category	RIN Code	Useful Life used in HROF Model
	Ground Outdoor / Indoor Chamber Mounted; > 132 kV ; < = 100 MVA		N/A
	Ground Outdoor / Indoor Chamber Mounted; > 132 kV ; > 100 MVA		N/A
	POLE MOUNTED ; < = 11kV ; > 60 kVA AND < = 600 kVA ; MULTIPLE PHASE	P-11-M-M	50.000
	POLE MOUNTED ; 22kV ; > 60 kVA AND < = 600 kVA ; MULTIPLE PHASE	P-22-M-M	50.000
	KIOSK MOUNTED ; 11kV ; > 60 kVA AND < = 600 kVA ; MULTIPLE PHASE	K-11-M-M	45.000
	KIOSK MOUNTED ; 22kV ; > 60 kVA AND < = 600 kVA ; MULTIPLE PHASE	K-22-M-M	45.000
	Ground; 11kV; > 60 kVA AND < = 600 kVA; Multi Phase	G-11-M-M	55.000
	Indoor; <=11kV; > 60 kVA AND < = 600 kVA; Multi Phase	I-11-M-M	55.000
	Ground Outdoor/Indoor Chamber Mounted; <=11kV; >600 kVA; Multi Phase	I-11-H-M	55.000
	Ground; 11kV; 5MVA	ZSS-PRIM11-5	55.000
	Indoor; 22 kV ; > 600 kVA ; Single Phase	I-22-H-S	55.000
	Ground; 22 kV ; < = 60 kVA ; Multiple Phase	G-22-L-M	55.000
	Ground; 22kV; > 60 kVA AND < = 600 kVA; Multi Phase	G-22-M-M	55.000
	Indoor; 22kV; > 60 kVA AND < = 600 kVA; Multi Phase	I-22-M-M	55.000
	Ground Outdoor/Indoor Chamber Mounted; 22kV ; > 600 kVA ; MULTIPLE PHASE	G-22-H-M	55.000
	Ground Outdoor / Indoor Chamber Mounted; 22 kV ; < = 15 MVA	ZSS-PRIM22-15	55.000
	POWER TRANSFORMER - BUSHING	TX_BUSHING	5.000
	POWER TRANSFORMER - OLTC	TX_OLTC	45.000
	Underground; 11kV; > 60 kVA AND < = 600 kVA; Multi Phase	U-11-M-M	55.000
	Other		0.000
DISTRIBUTION SWITCHGEAR	< = 11 kV ; Fuse	HVSW-FUS-11	30.000
	< = 11 kV ; Switch		35.000
	< = 11 kV ; Circuit Breaker		45.000
	> 11 kV & < = 22 kV ; Switch		34.000
	> 11 kV & < = 22 kV ; Circuit Breaker		45.000
	> 22 kV & < = 33 kV ; Switch		N/A
	> 22 kV & < = 33 kV ; Circuit Breaker		N/A
	> 33 kV & < = 66 kV ; Switch	ZSS-ISO-66	45.000
	> 33 kV & < = 66 kV ; Circuit Breaker	ZSS-CB-66-OUT	45.000
	> 66 kV & < = 132 kV ; Switch		N/A
	> 66 kV & < = 132 kV ; Circuit Breaker		N/A
	> 132 kV ; Switch		N/A
	> 132 kV ; Circuit Breaker		N/A
	< ≈ 1 kV ; SWITCH GEAR	LVISO-Switch	35.000
	< ≈ 1 kV ; SWITCH; POLE MOUNTED	LVISO-Pole	35.000
	O/H Isolators -HV - 11kV	HVSW-ISO-11	35.000

Asset Class	Asset Category	RIN Code	Useful Life used in HROF Model
	O/H Load Break Switches - HV - 11kV	HVSW-LB-11	35.000
	Ring Main Unit - 11kV	HVSW-RMU-11	35.000
	< = 11 kV ; REMOTE CONTROL GAS SWITCH	HVSW-RCGS-11	35.000
	Indoor Circuit Breakers 11kV	ZSS-CB-11-IN	55.000
	ACR's 11kV	ACR-11	40.000
	> 11 kV & < = 22 kV ; REMOTE CONTROL GAS SWITCH	HVSW-RCGS-22	35.000
	O/H Isolators -HV - 22kV	HVSW-ISO-22	35.000
	O/H Load Break Switches - HV - 22kV	HVSW-LB-22	35.000
	Ring Main Unit - 22kV	HVSW-RMU-22	35.000
	O/H Fuse Units - HV - 22kV	HVSW-FUS-22	30.000
	>= 11 kV & < = 22 kV ; LINE CAPACITORS; CONTROLLERS AND VACUUM SWITCHES	HV-LineCaps	30.000
	Outdoor Circuit Breakers 22kV	ZSS-CB-22-OUT	45.000
	Indoor Circuit Breakers 22kV	ZSS-CB-22-IN	55.000
	ACR's - 22kV	ACR-22	40.000
	Other		N/A
PUBLIC LIGHTING	Luminaires ; Major Road	PL-LUM-MAIN	20.000
	Luminaires ; Minor Road	PL-LUM-MIN	20.000
	Brackets ; Major Road	PL-BRACKET-MAIN	20.000
	Brackets ; Minor Road	PL-BRACKET-MIN	20.000
	Lamps ; Major Road		N/A
	Lamps ; Minor Road		N/A
	Poles / Columns ; Major Road	PL-POL-MAIN	50.000
	Poles / Columns ; Minor Road	PL-POL-MIN	50.000
	Other		0.000
PROTECTION SCADA CONTROL	Field Devices		N/A
	Local Network Wiring Assets		N/A
	Communications Network Assets		N/A
	Master Station Assets		N/A
	Communications Site Infrastructure		N/A
	Communications Linear Assets		N/A
	AFLC		N/A
	Relays - Analogue	RELAY_ANA	20.900
	Relays - Electromechanical	RELAY_ELE	51.700
	Relays - Digital/Microprocessor	RELAY_DIG	18.300
	SCADA	SCADA	20.000
	SCADA - Operational Energy Meters	OP_METER	20.000
	POWER QUALITY METERS	PQ METER	20.000
	DC DISTRIBUTION BOARDS	DC BOARD	40.000
	AC DISTRIBUTION BOARDS	AC BOARD	40.000

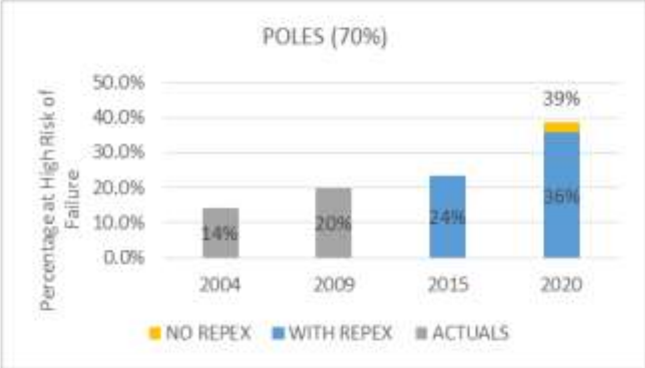
Asset Class	Asset Category	RIN Code	Useful Life used in HROF Model
	ZSS BATTERY BANKS	BATTERY	10.000
	ZSS BATTERY CHARGERS	CHARGER	20.000
	ZSS CONTROLLERS	ZSS-Cont	25.000
	COMMUNICATION FIBRE OPTIC CABLE	SUP-FOC	40.000
	COMMUNICATION – SUPERVISORY METALLIC CABLE	SUP-MET	40.000
	Radio Towers	RADIO	20.000
	Other		N/A
ZONE SUBSTATIONS	Buildings	ZSS-Build	59.200
	Civil	ZSS-Civil	45.000
	Capacitor Banks - Large	ZSS-CAP	60.000
	Fences	ZSS-Fence	30.000
	CTs and VTs	ZSS-Inst	50.000
	NER's	ZSS-NER	40.000

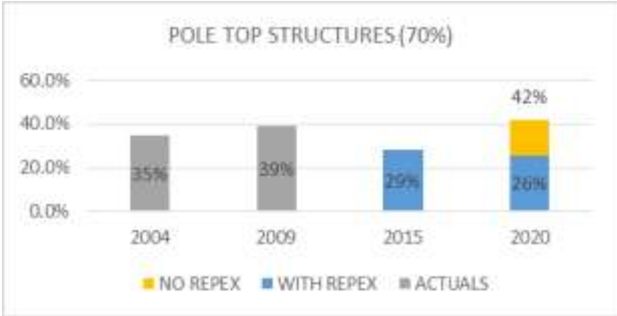
Appendix C: Sensitivity Analysis for HROF Threshold

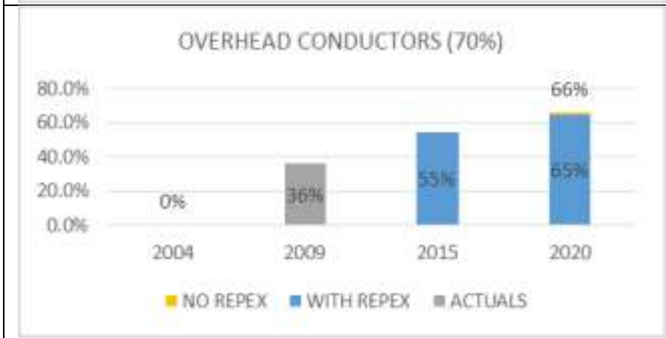
Scenario 1

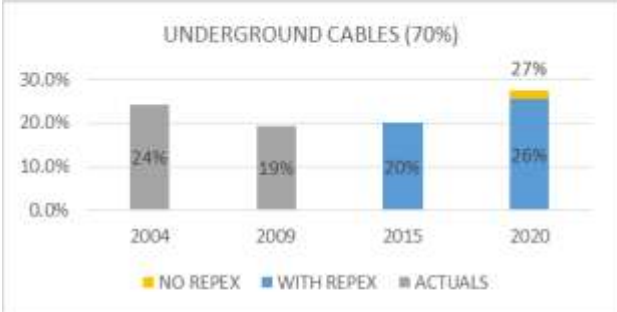
Metric	Percentage of Assets at High Risk Of Failure (Value)				
Ages	Weibull Lives				
Rates	EDPR Rates (Blended Project and Unitised)				
Threshold	70%				
Year	**2004**	**2009**	**2015**	**2020**	
With or No Replacement				**With REPEX**	**NO REPEX**
Poles	14%	20%	24%	36%	39%
Pole Top Structures	35%	39%	29%	26%	42%
Overhead Conductors	0%	36%	55%	65%	66%
Underground Cables	24%	19%	20%	26%	27%
Distribution Transformers	11%	26%	18%	23%	29%
Zone Substation Transformers	56%	63%	52%	44%	60%
Distribution Switchgear	28%	11%	27%	40%	46%
Zone Substation Switchgear	71%	11%	60%	48%	62%
Protection, SCADA and Control	57%	15%	30%	35%	51%
Service Lines	39%	34%	9%	1%	15%
Network	22%	29%	31%	37%	42%

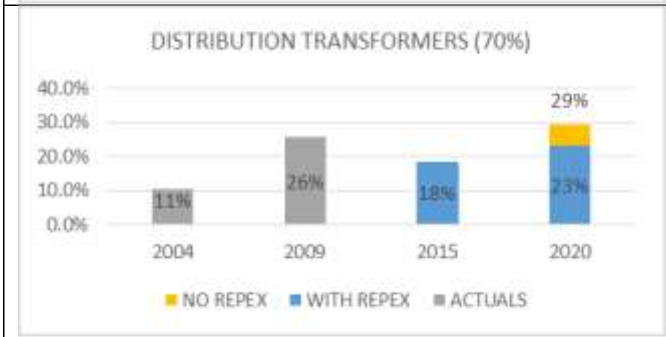
Metric	Percentage of Assets at High Risk Of Failure (Value)
Ages	Wielbul Lives
Rates	EDPR Rates (Blended Project and Unitised)
Threshold	70 % of Expected Asset Life

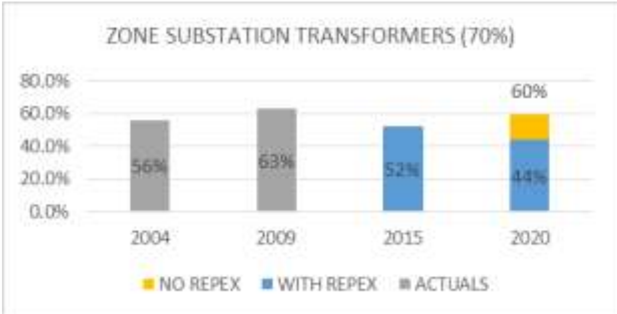


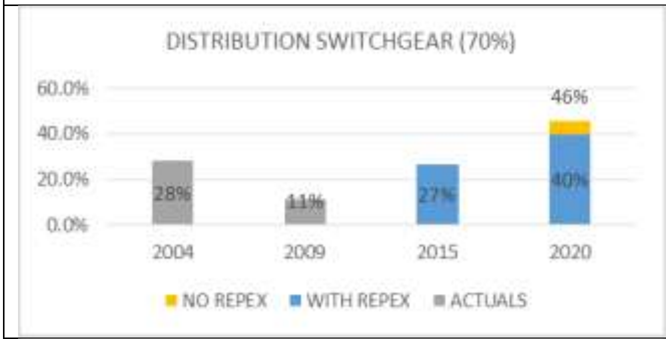


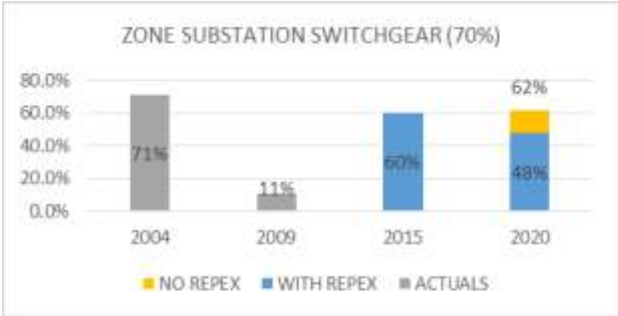


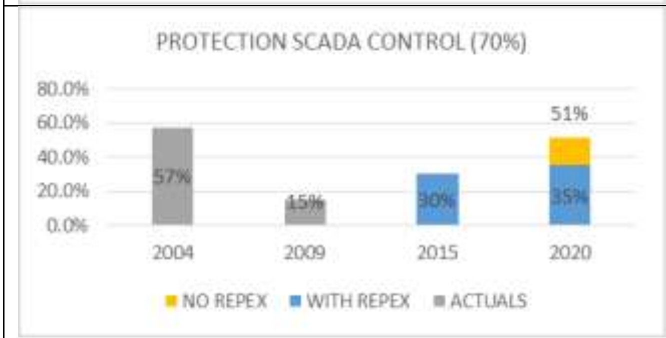


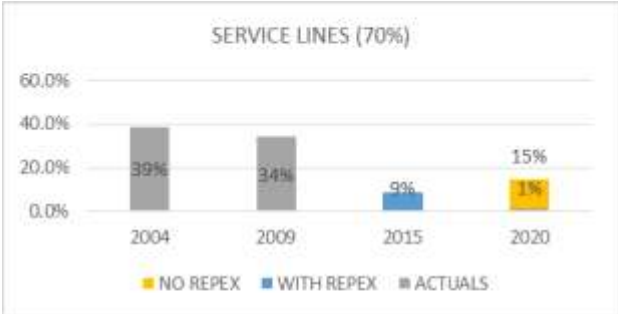


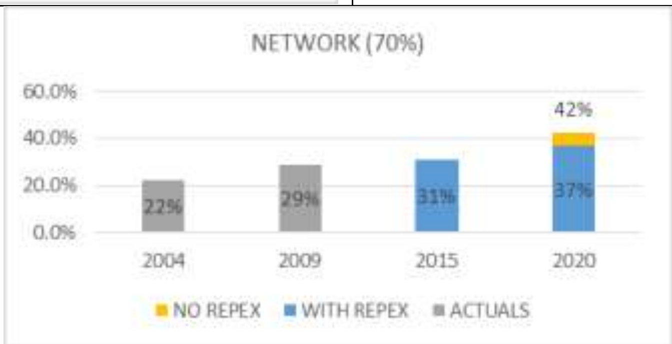










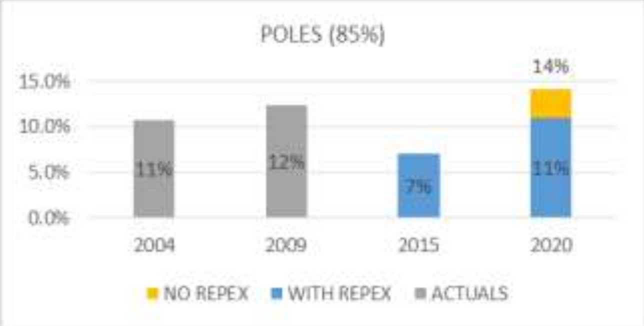


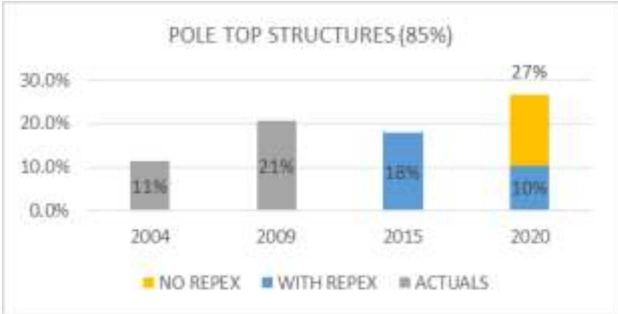
Using a more conservative risk threshold of 70% on the expected Life of assets, the trend from 2015 to 2020 even with replacement Expenditure is increasing for all asset class except for Zone SubstationTransfomers and Service Lines

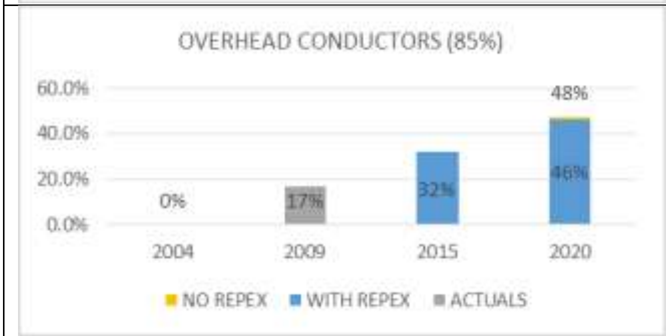
Scenario 2

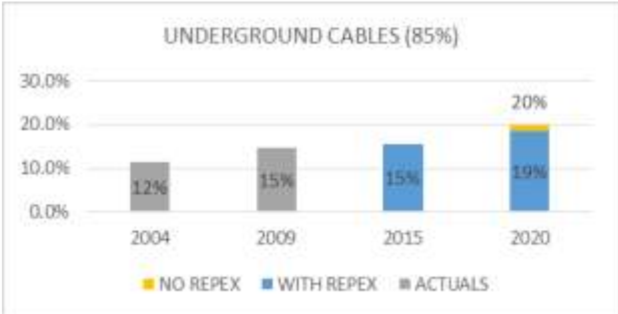
Metric	Percentage of Assets at High Risk Of Failure (Value)				
Ages	Weibull Lives				
Rates	EDPR Rates (Blended Project and Unitised)				
Threshold	85%				
Year	**2004**	**2009**	**2015**	**2020**	
With or No Replacement				**With REPEX**	**NO REPEX**
Poles	11%	12%	7%	11%	14%
Pole Top Structures	11%	21%	18%	10%	27%
Overhead Conductors	0%	17%	32%	46%	48%
Underground Cables	12%	15%	15%	19%	20%
Distribution Transformers	3%	13%	7%	10%	15%
Zone Substation Transformers	24%	16%	34%	37%	52%
Distribution Switchgear	21%	8%	16%	22%	28%
Zone Substation Switchgear	46%	8%	51%	47%	60%
Protection, SCADA and Control	51%	11%	22%	25%	37%
Service Lines	10%	13%	5%	0%	8%
Network	12%	17%	19%	23%	28%

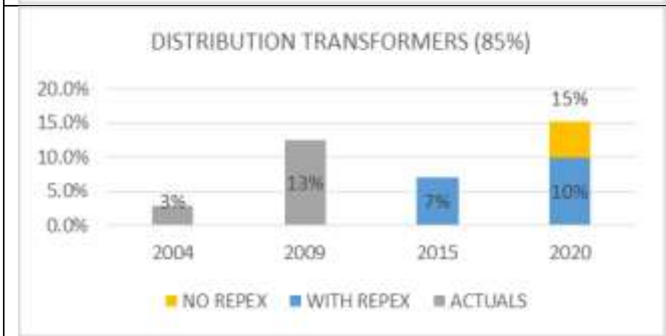
Metric	Percentage of Assets at High Risk Of Failure (Value)
Ages	Weibull Lives
Rates	EDPR Rates (Blended Project and Unitised)
Threshold	85 % of Expected Asset Life

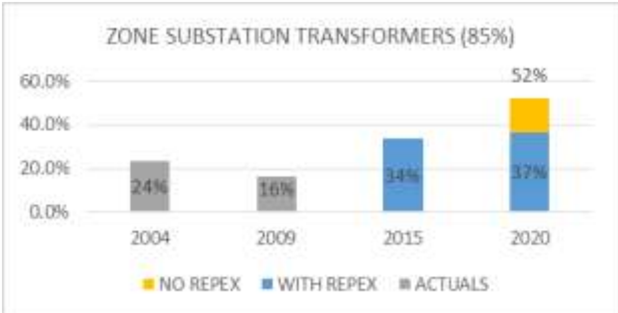


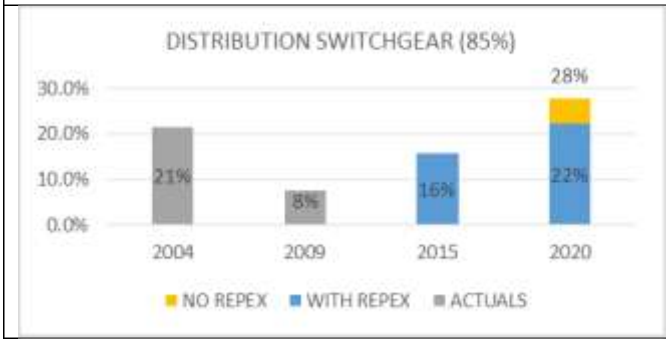


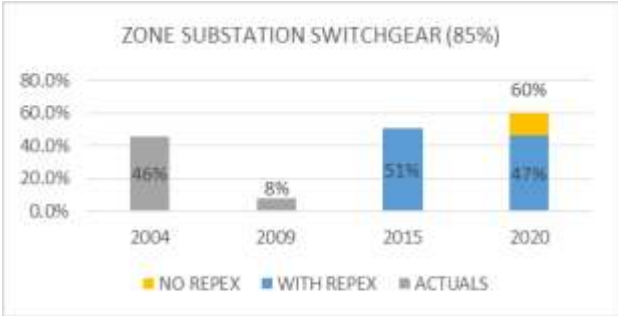


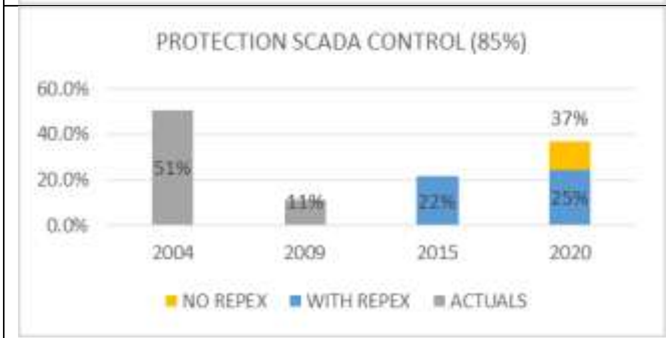


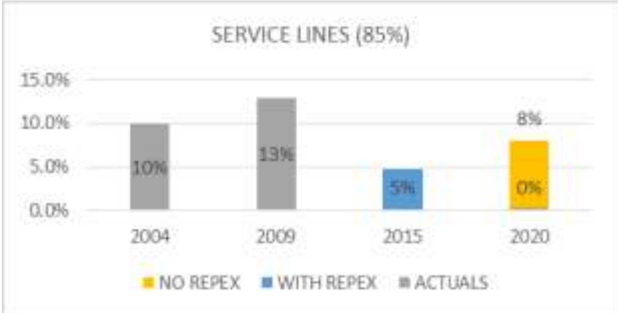


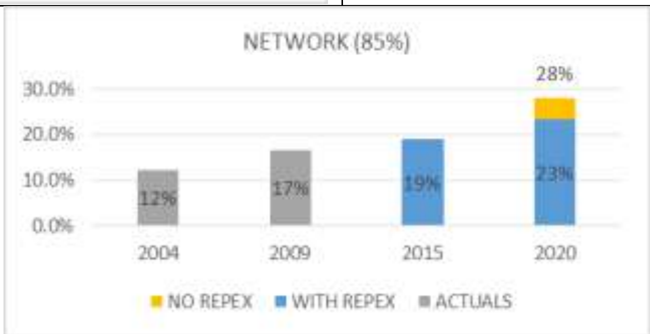



DISTRIBUTION SWITCHGEAR (85%)
30.0%
20.0%
10.0%
0.0%
21%
8%
16%
22%
28%
2004
2009
2015
2020
NO REPEX
WITH REPEX
ACTUALS


ZONE SUBSTATION SWITCHGEAR (85%)
80.0%
60.0%
40.0%
20.0%
0.0%
46%
8%
51%
47%
60%
2004
2009
2015
2020
NO REPEX
WITH REPEX
ACTUALS


PROTECTION SCADA CONTROL (85%)
60.0%
40.0%
20.0%
0.0%
51%
11%
22%
25%
37%
2004
2009
2015
2020
NO REPEX
WITH REPEX
ACTUALS

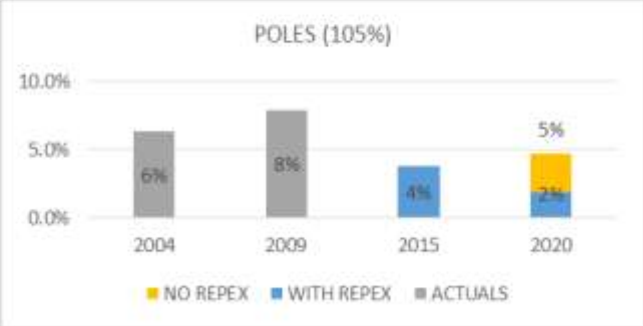

SERVICE LINES (85%)
15.0%
10.0%
5.0%
0.0%
10%
13%
5%
0%
8%
2004
2009
2015
2020
NO REPEX
WITH REPEX
ACTUALS

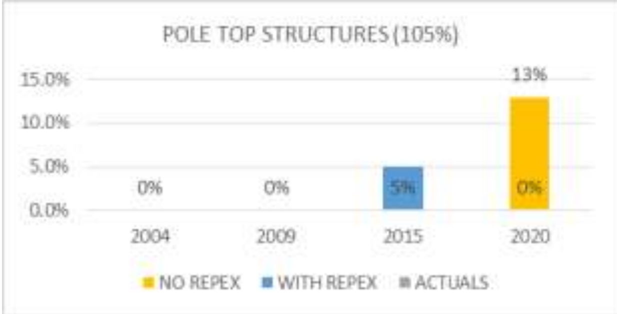

NETWORK (85%)
30.0%
20.0%
10.0%
0.0%
12%
17%
19%
23%
28%
2004
2009
2015
2020
NO REPEX
WITH REPEX
ACTUALS

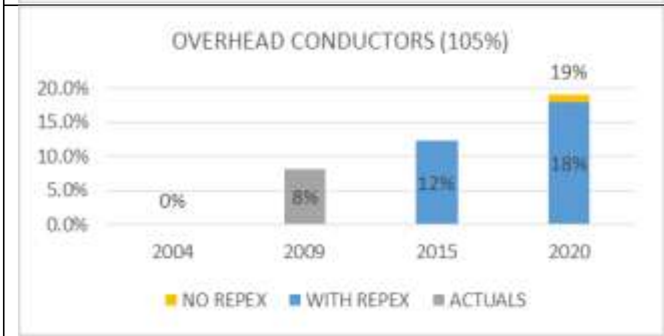
Scenario 3

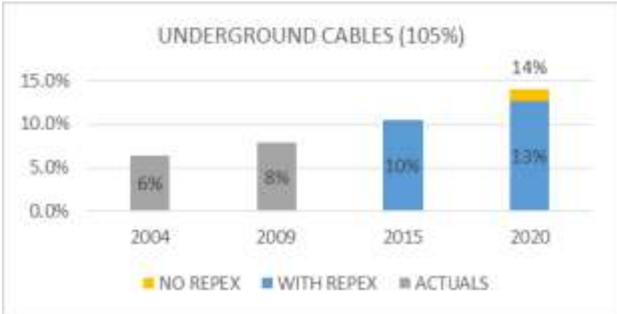
Metric	Percentage of Assets at High Risk Of Failure (Value)				
Ages	Weibull Lives				
Rates	EDPR Rates (Blended Project and Unitised)				
Threshold	105%				
Year	**2004**	**2009**	**2015**	**2020**	
With or No Replacement				**With REPEX**	**NO REPEX**
Poles	6%	8%	4%	2%	5%
Pole Top Structures	0%	0%	5%	0%	13%
Overhead Conductors	0%	8%	12%	18%	19%
Underground Cables	6%	8%	10%	13%	14%
Distribution Transformers	1%	3%	1%	1%	4%
Zone Substation Transformers	2%	0%	2%	0%	3%
Distribution Switchgear	13%	3%	7%	9%	14%
Zone Substation Switchgear	13%	3%	32%	29%	42%
Protection, SCADA and Control	47%	5%	9%	10%	18%
Service Lines	0%	0%	1%	0%	4%
Network	6%	7%	9%	10%	13%

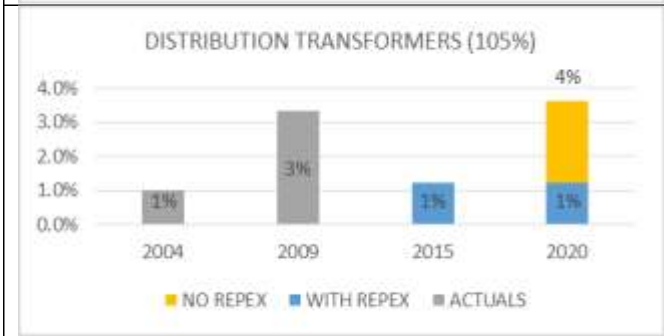
Metric	Percentage of Assets at High Risk Of Failure (Value)
Ages	Weibull Lives
Rates	EDPR Rates (Blended Project and Unitised)
Threshold	105 % of Expected Asset Life

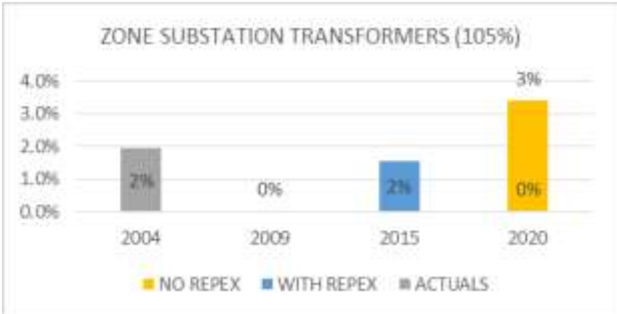


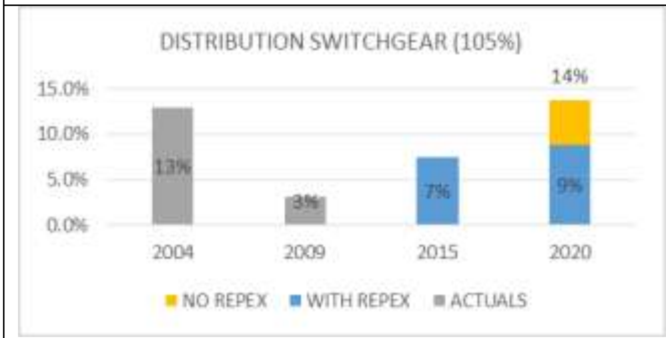


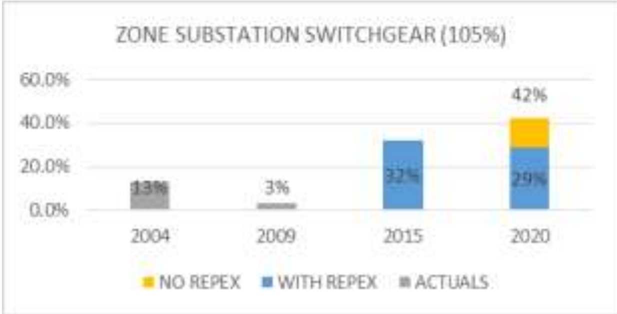


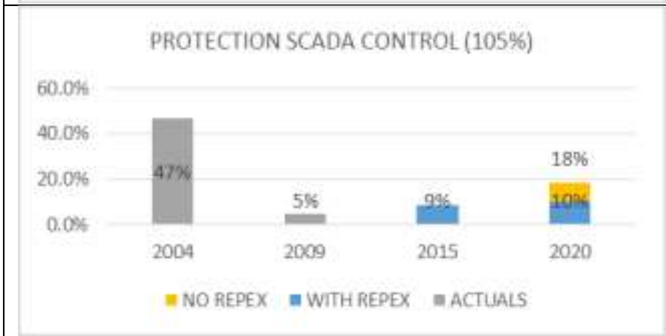


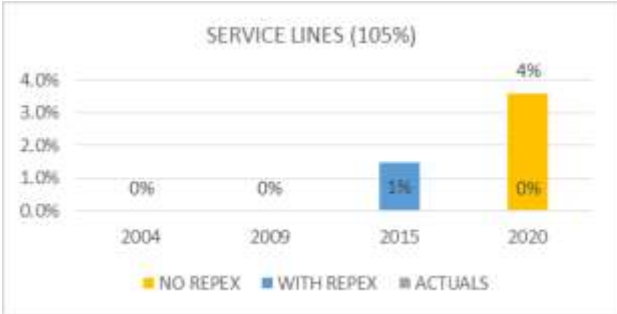


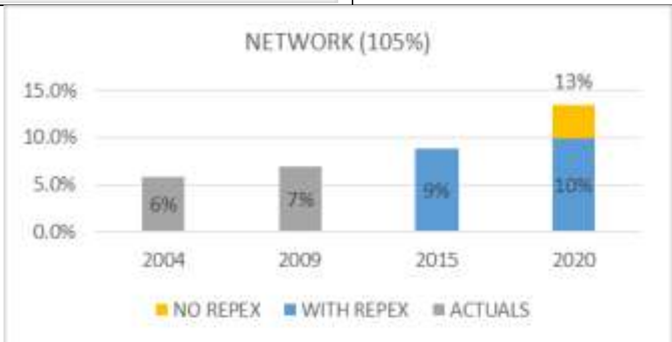



DISTRIBUTION SWITCHGEAR (105%)
15.0%
10.0%
5.0%
0.0%
13%
3%
7%
9%
14%
2004
2009
2015
2020
NO REPEX
WITH REPEX
ACTUALS


ZONE SUBSTATION SWITCHGEAR (105%)
60.0%
40.0%
20.0%
0.0%
13%
3%
32%
29%
42%
2004
2009
2015
2020
NO REPEX
WITH REPEX
ACTUALS


PROTECTION SCADA CONTROL (105%)
60.0%
40.0%
20.0%
0.0%
47%
5%
9%
10%
18%
2004
2009
2015
2020
NO REPEX
WITH REPEX
ACTUALS

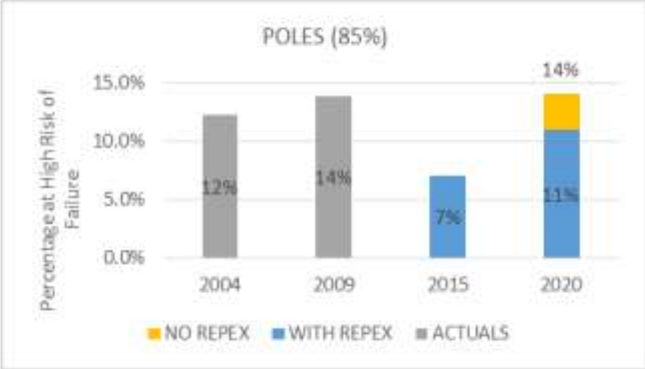

SERVICE LINES (105%)
4.0%
3.0%
2.0%
1.0%
0.0%
0%
0%
1%
0%
4%
2004
2009
2015
2020
NO REPEX
WITH REPEX
ACTUALS

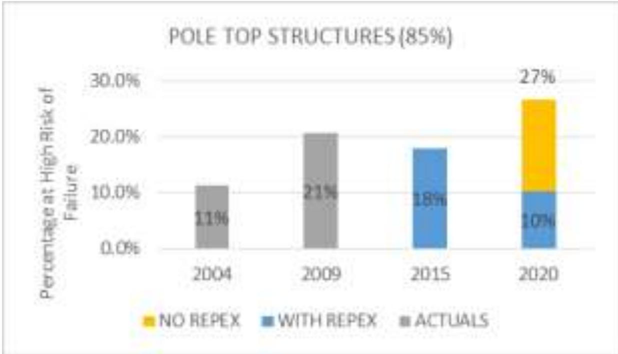

NETWORK (105%)
15.0%
10.0%
5.0%
0.0%
6%
7%
9%
10%
13%
2004
2009
2015
2020
NO REPEX
WITH REPEX
ACTUALS

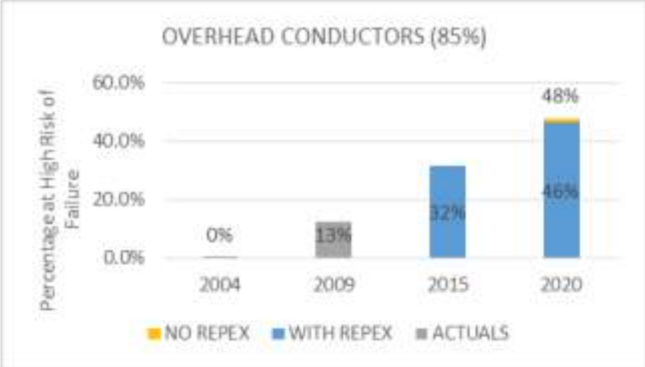
Scenario 4

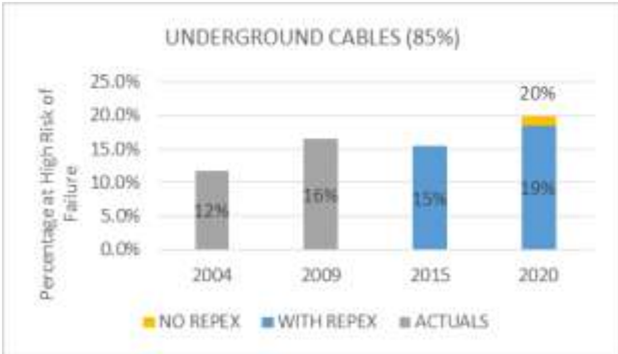
Metric	Percentage of Assets at High Risk Of Failure (Value)				
Ages	Wielbul Lives				
Rates	2009 Rates				
Threshold	85%				
Year	**2004**	**2009**	**2015**	**2020**	
With or No Replacement				**With REPEX**	**NO REPEX**
Poles	12%	14%	7%	11%	14%
Pole Top Structures	11%	21%	18%	10%	27%
Overhead Conductors	0%	13%	32%	46%	48%
Underground Cables	12%	16%	15%	19%	20%
Distribution Transformers	3%	14%	7%	10%	15%
Zone Substation Transformers	24%	16%	34%	37%	52%
Distribution Switchgear	18%	12%	16%	22%	28%
Zone Substation Switchgear	37%	12%	51%	47%	60%
Protection, SCADA and Control	67%	18%	22%	25%	37%
Service Lines	10%	13%	5%	0%	8%
Network	14%	18%	19%	23%	28%

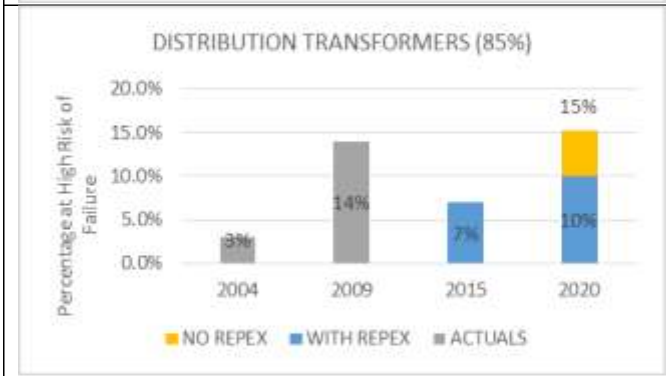
Metric	Percentage of Assets at High Risk Of Failure (Value)
Ages	2004 Expected Lives
Rates	EDPR Rates (Blended Project and Unitised)
Threshold	105%

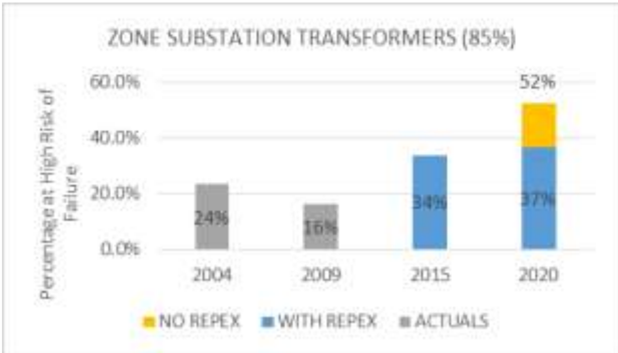


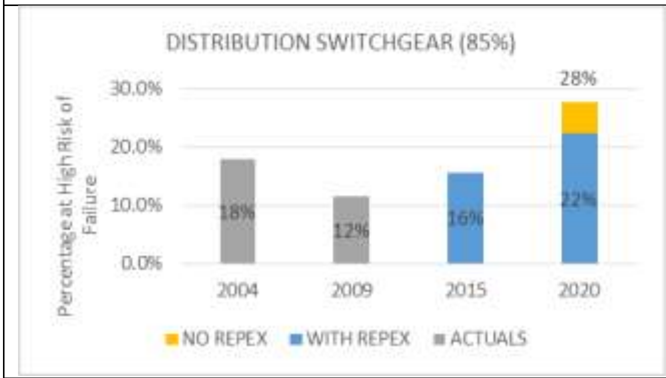


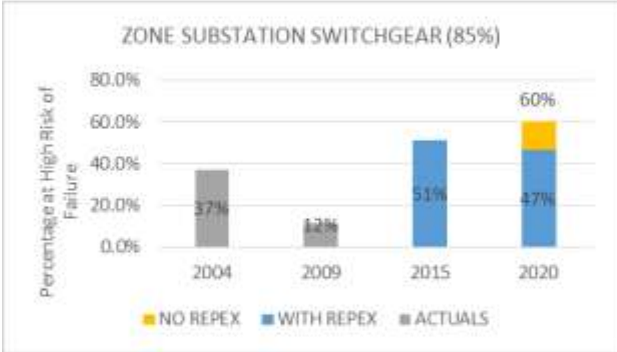


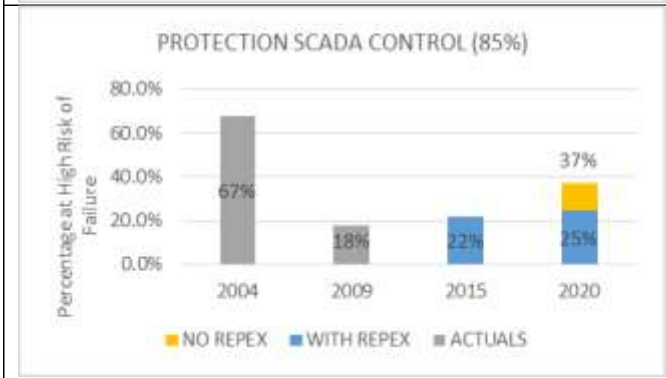


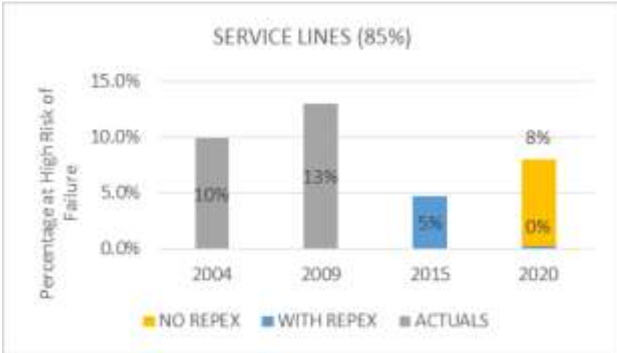


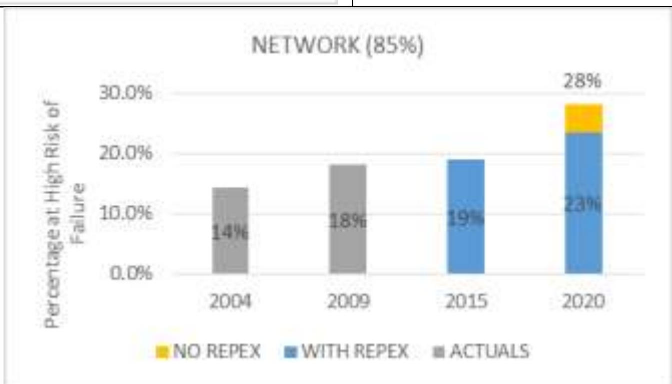



DISTRIBUTION SWITCHGEAR (85%)
Percentage at High Risk of Failure
30.0%
20.0%
10.0%
0.0%
2004
2009
2015
2020
18%
12%
16%
22%
28%
NO REPEX
WITH REPEX
ACTUALS


ZONE SUBSTATION SWITCHGEAR (85%)
Percentage at High Risk of Failure
80.0%
60.0%
40.0%
20.0%
0.0%
2004
2009
2015
2020
37%
12%
51%
47%
60%
NO REPEX
WITH REPEX
ACTUALS


PROTECTION SCADA CONTROL (85%)
Percentage at High Risk of Failure
80.0%
60.0%
40.0%
20.0%
0.0%
2004
2009
2015
2020
67%
18%
22%
25%
37%
NO REPEX
WITH REPEX
ACTUALS

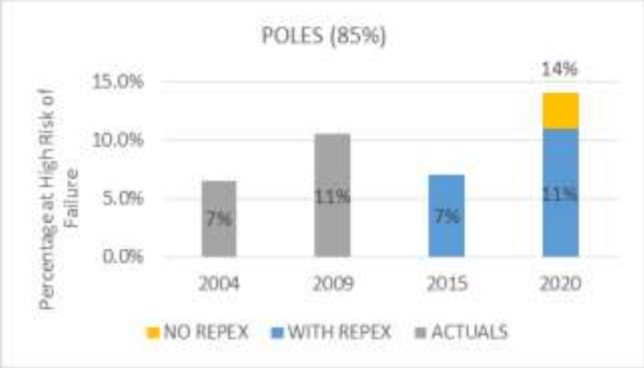

SERVICE LINES (85%)
Percentage at High Risk of Failure
15.0%
10.0%
5.0%
0.0%
2004
2009
2015
2020
10%
13%
5%
0%
8%
NO REPEX
WITH REPEX
ACTUALS

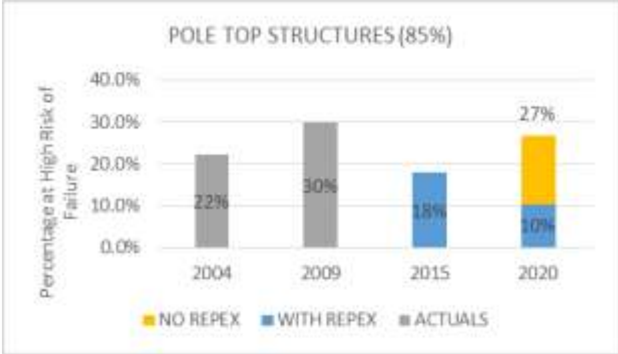

NETWORK (85%)
Percentage at High Risk of Failure
30.0%
20.0%
10.0%
0.0%
2004
2009
2015
2020
14%
18%
19%
23%
28%
NO REPEX
WITH REPEX
ACTUALS

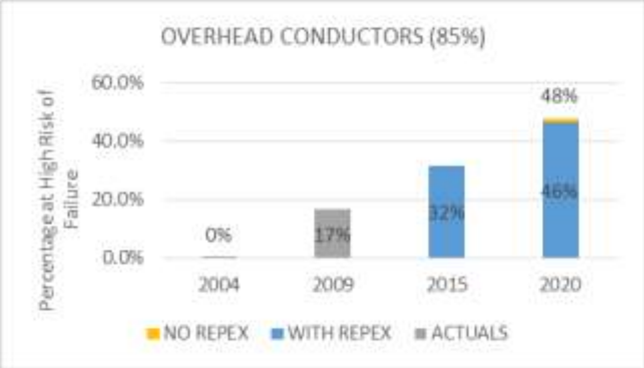
Scenario 5

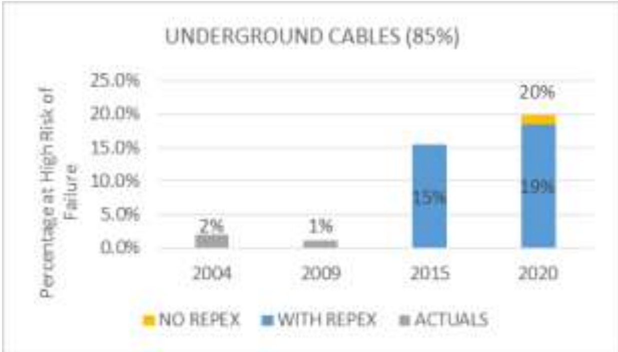
Metric	Percentage of Assets at High Risk Of Failure (Value)				
Ages	2009 Expected Lives				
Rates	EDPR Rates (Blended Project and Unitised)				
Threshold	85%				
Year	**2004**	**2009**	**2015**	**2020**	
With or No Replacement				**With REPEX**	**NO REPEX**
Poles	7%	11%	7%	11%	14%
Pole Top Structures	22%	30%	18%	10%	27%
Overhead Conductors	0%	17%	32%	46%	48%
Underground Cables	2%	1%	15%	19%	20%
Distribution Transformers	3%	13%	7%	10%	15%
Zone Substation Transformers	24%	25%	34%	37%	52%
Distribution Switchgear	27%	10%	16%	22%	28%
Zone Substation Switchgear	23%	10%	51%	47%	60%
Protection, SCADA and Control	32%	5%	22%	25%	37%
Service Lines	31%	29%	5%	0%	8%
Network	9%	14%	19%	23%	28%

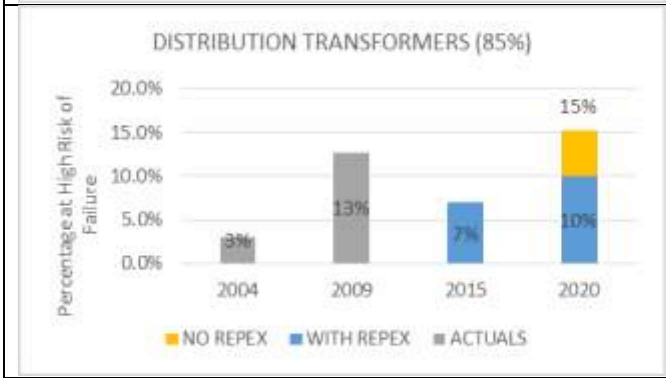
Metric	Percentage of Assets at High Risk Of Failure (Value)
Ages	2009 Expected Lives
Rates	EDPR Rates (Blended Project and Unitised)
Threshold	85%

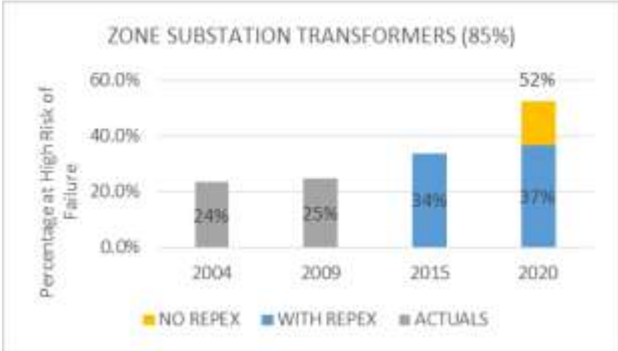


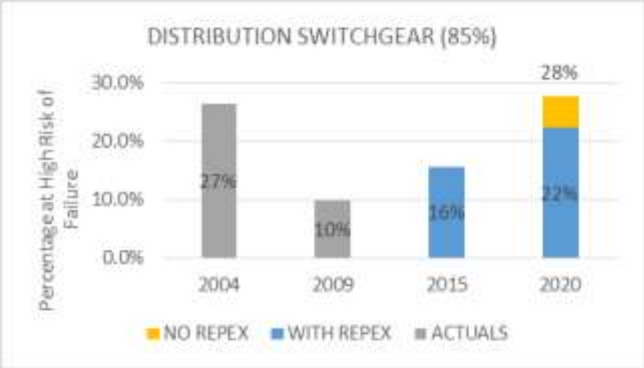


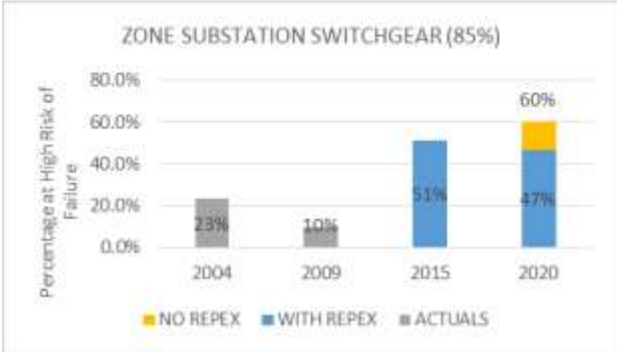


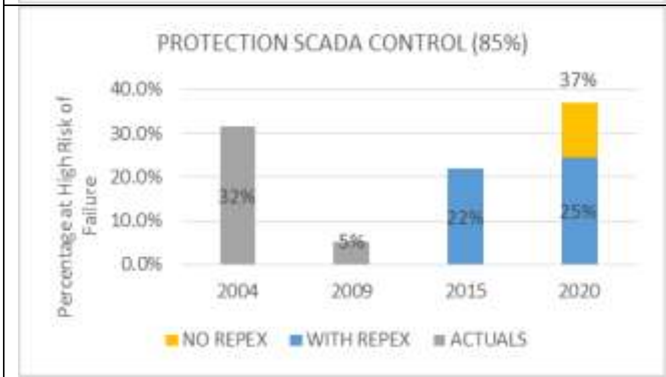


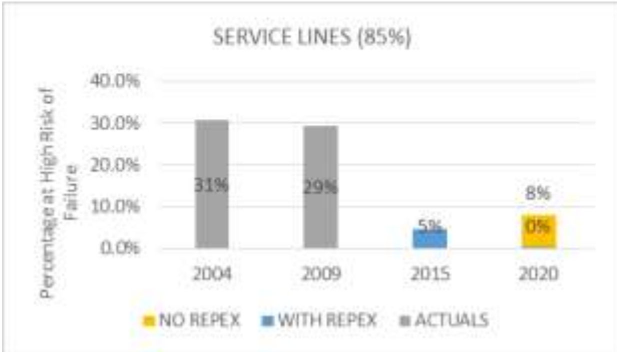


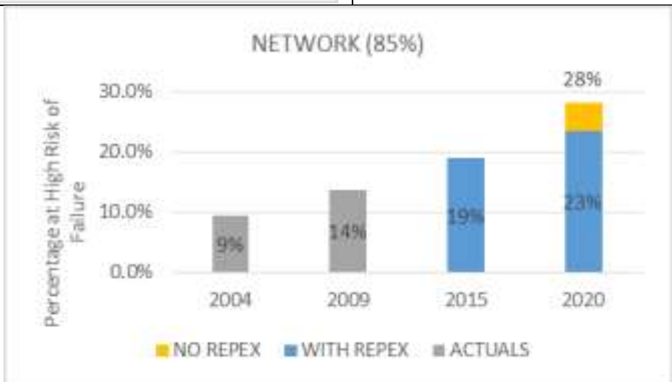



DISTRIBUTION SWITCHGEAR (85%)
Percentage at High Risk of Failure
30.0%
20.0%
10.0%
0.0%
2004
2009
2015
2020
27%
10%
16%
22%
28%
NO REPEX
WITH REPEX
ACTUALS


ZONE SUBSTATION SWITCHGEAR (85%)
Percentage at High Risk of Failure
80.0%
60.0%
40.0%
20.0%
0.0%
2004
2009
2015
2020
23%
10%
51%
47%
60%
NO REPEX
WITH REPEX
ACTUALS


PROTECTION SCADA CONTROL (85%)
Percentage at High Risk of Failure
40.0%
30.0%
20.0%
10.0%
0.0%
2004
2009
2015
2020
32%
5%
22%
25%
37%
NO REPEX
WITH REPEX
ACTUALS

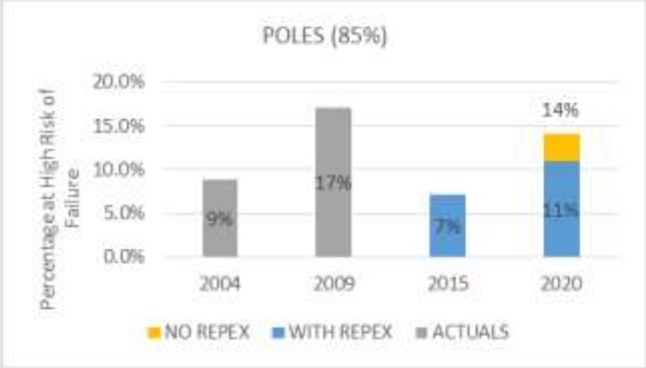

SERVICE LINES (85%)
Percentage at High Risk of Failure
40.0%
30.0%
20.0%
10.0%
0.0%
2004
2009
2015
2020
31%
29%
5%
0%
8%
NO REPEX
WITH REPEX
ACTUALS

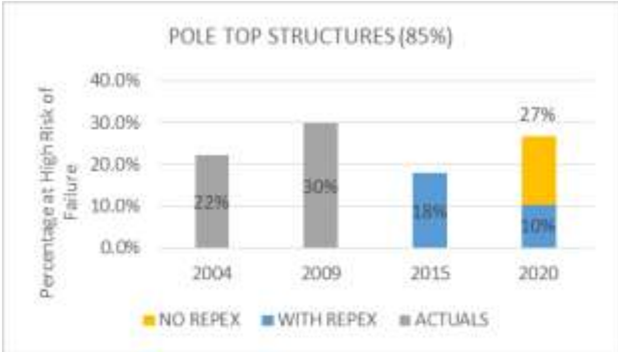

NETWORK (85%)
Percentage at High Risk of Failure
30.0%
20.0%
10.0%
0.0%
2004
2009
2015
2020
9%
14%
19%
23%
28%
NO REPEX
WITH REPEX
ACTUALS

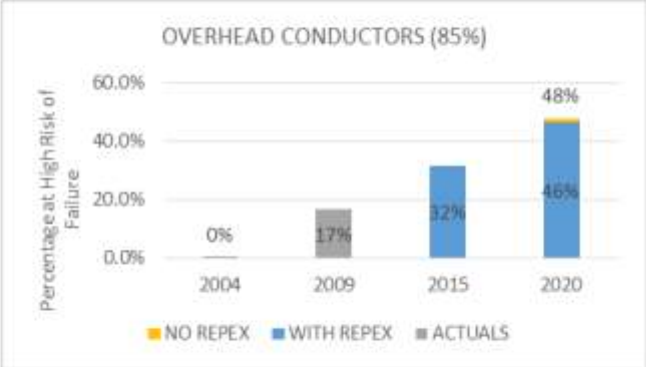
Scenario 6

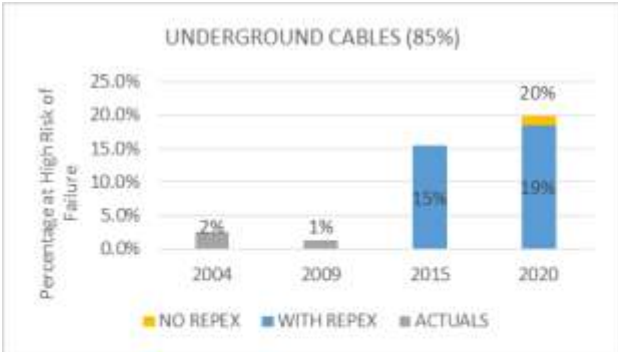
Metric	Percentage of Assets at High Risk Of Failure (Value)				
Ages	2004 Expected Lives				
Rates	EDPR Rates (Blended Project and Unitised)				
Threshold	85%				
Year	**2004**	**2009**	**2015**	**2020**	
With or No Replacement				**With REPEX**	**NO REPEX**
Poles	9%	17%	7%	11%	14%
Pole Top Structures	22%	30%	18%	10%	27%
Overhead Conductors	0%	17%	32%	46%	48%
Underground Cables	2%	1%	15%	19%	20%
Distribution Transformers	2%	7%	7%	10%	15%
Zone Substation Transformers	24%	25%	34%	37%	52%
Distribution Switchgear	17%	8%	16%	22%	28%
Zone Substation Switchgear	17%	8%	51%	47%	60%
Protection, SCADA and Control	32%	15%	22%	25%	37%
Service Lines	0%	4%	5%	0%	8%
Network	9%	14%	19%	23%	28%

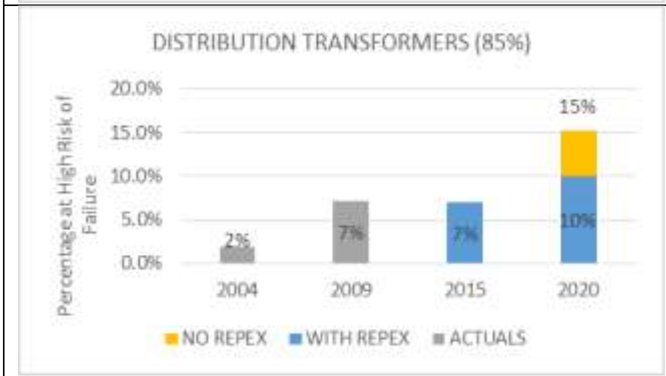
Metric	Percentage of Assets at High Risk Of Failure (Value)
Ages	2004 Expected Lives
Rates	EDPR Rates (Blended Project and Unitised)
Threshold	85%

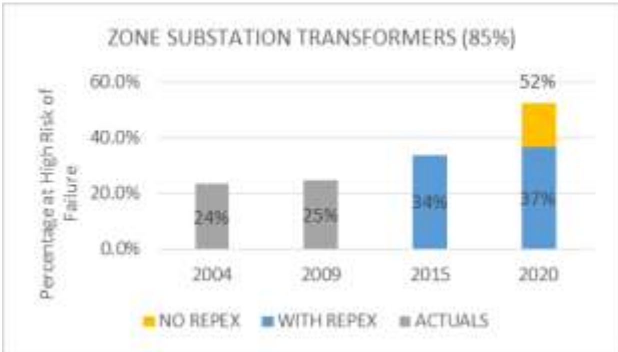


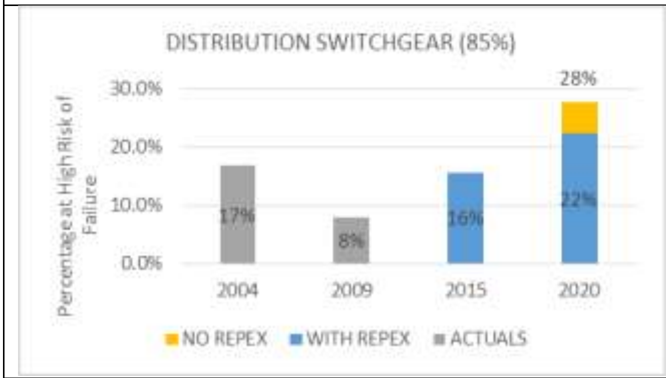


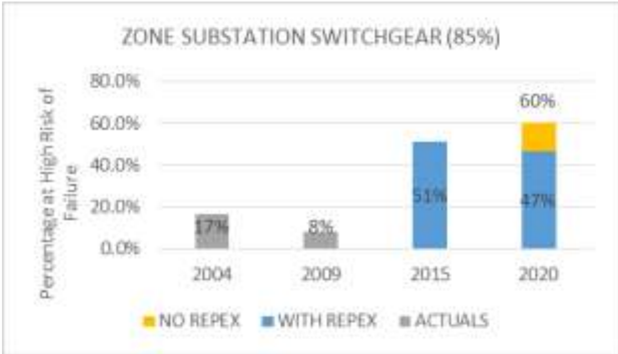


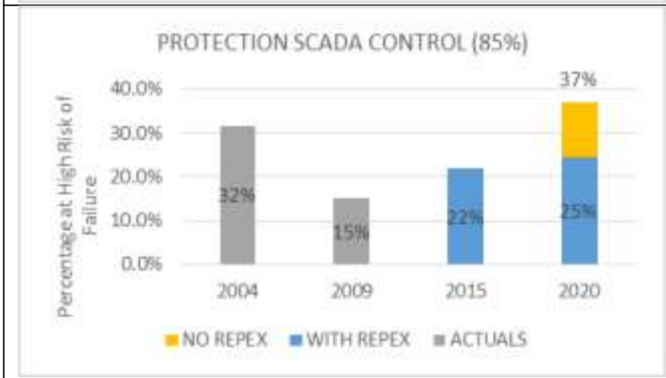


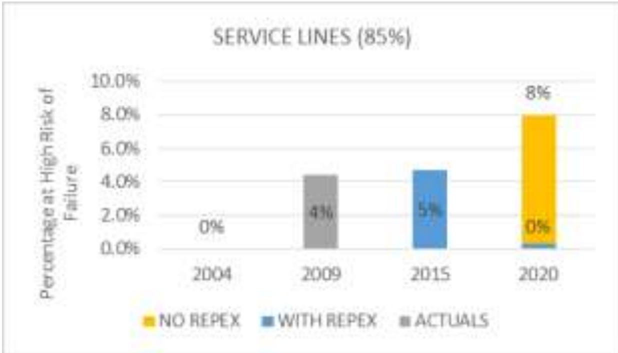


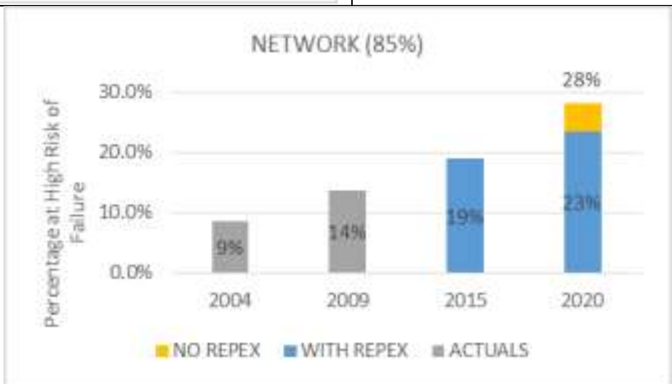



DISTRIBUTION SWITCHGEAR (85%)
Percentage at High Risk of Failure
30.0%
20.0%
10.0%
0.0%
17%
8%
16%
22%
28%
2004
2009
2015
2020
NO REPEX
WITH REPEX
ACTUALS


ZONE SUBSTATION SWITCHGEAR (85%)
Percentage at High Risk of Failure
80.0%
60.0%
40.0%
20.0%
0.0%
17%
8%
51%
47%
60%
2004
2009
2015
2020
NO REPEX
WITH REPEX
ACTUALS


PROTECTION SCADA CONTROL (85%)
Percentage at High Risk of Failure
40.0%
30.0%
20.0%
10.0%
0.0%
32%
15%
22%
25%
37%
2004
2009
2015
2020
NO REPEX
WITH REPEX
ACTUALS


SERVICE LINES (85%)
Percentage at High Risk of Failure
10.0%
8.0%
6.0%
4.0%
2.0%
0.0%
0%
4%
5%
0%
8%
2004
2009
2015
2020
NO REPEX
WITH REPEX
ACTUALS


NETWORK (85%)
Percentage at High Risk of Failure
30.0%
20.0%
10.0%
0.0%
9%
14%
19%
23%
28%
2004
2009
2015
2020
NO REPEX
WITH REPEX
ACTUALS