Power transformer risk-based value assessment

Case for investment FY25 - 29
(Pre-optimisation)

October 2022

Investment Title	Power transformer reliability risk mitigation
Project number/code	
Portfolio	Repex
CFI Date	October 2022
Pre RIT-D	☐
Final CFI (Pre-optimisation)	☒
Other	☐

Version control and endorsements

Version	Date	Comments
0.21	20 October 2022	Draft issue for comment
1.1	27 October 2022	Initial approved issue

Author:

Digitally signed by Jonathan Cook
DN: cn=Jonathan Cook, c=AU,
email=Jonathan.cook@endeavourenergy.com.au
Date: 2022.11.03 13:46:51 +11'00'

Jonathan Cook

Engineer Asset Investment

Reviewed:

Mark Alexander

Digitally signed by Mark Alexander
DN: cn=Mark Alexander, c=AU, o=Endeavour
Energy, ou=Asset Planning and Performance,
email=mark.alexander@endeavourenergy.com.au
Date: 2022.11.03 13:25:25 +11'00'

Mark Alexander

Lead Engineer Asset Investment

Endorsed:

David Mate

Asset Performance Manager

Approved:

Digitally signed by Peter Langdon
DN: cn=Peter Langdon, c=AU, o=Endeavour
Energy, ou=Asset Planning and Performance,
email=peter.langdon@endeavourenergy.com.au
Date: 2022.11.06 09:31:14 +11'00'

Peter Langdon

Head of Asset Planning and Performance

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1. Executive summary

1.1 Recommendation

This case for investment (CFI) recommends the replacement of five power transformers across the network during the period of FY25 - FY29 to address the reliability and financial risks associated with this class of equipment failing whilst in service.

It is noted that this CFI is recommending investment to be included into the portfolio risk-based asset investment planning and optimisation process during the period of FY25 – FY29.

The total cost of the proposed risk-based works is estimated to be $7.16 million in real FY 23 terms.

This recommendation is made on the basis that the preferred solution represents the highest economic value (economic benefit) compared to other credible options.

Within this recommended program of works, each asset has been assessed individually for the risk it presents and an investment solution specific to the design and location of the asset has been proposed. Furthermore, this is an ongoing program with no material change proposed across the asset type and the highest cost credible option at each site falls below the threshold for application of the Regulatory Investment Test for Distribution (RIT-D) (currently $6.0 million). Therefore, the RIT-D is not applicable to this program.

A further allowance of $8.16 million is proposed for the replacement of power transformers that fail unexpectedly in a non-repairable manner during the FY25 – FY29 period giving a total proposed investment of $15.32 million.

1.2 Identified need

Endeavour Energy has a fleet of 457 power transformers in service at primary voltages of 132kV, 66kV and 33kV. The transformers are in service in zone and transmission substations and customer substations and are used to transform electricity from one voltage to usually a lower voltage to allow for its distribution to customers.

Power transformers can suffer a range of failure modes, many of which are repairable. However, the failures which will generally end the life of the transformer include:

- Breakdown of the insulation around the windings due to natural degradation over time and service;
- Breakdown of the insulation around the windings due to movement of the windings due to the passage of fault current;
- Mechanical or insulation failure in the tap-changer;
- Non-repairable failures of the secondary systems built into the transformer;
- Loss of integrity of the tank (usually due to corrosion damage).

Transformers are identified for risk-based retirement and replacement when the net present value (NPV) of the intervention is positive and reaches its maximum value.

Replacement transformers are new units. Spare units are kept on hand to replace transformers which fail unexpectedly whilst in service.

The safety and environmental risks associated with failure are generally very low and therefore risk-based replacement is driven by the likelihood of causing loss of supply to customers and the value of that unserved energy.

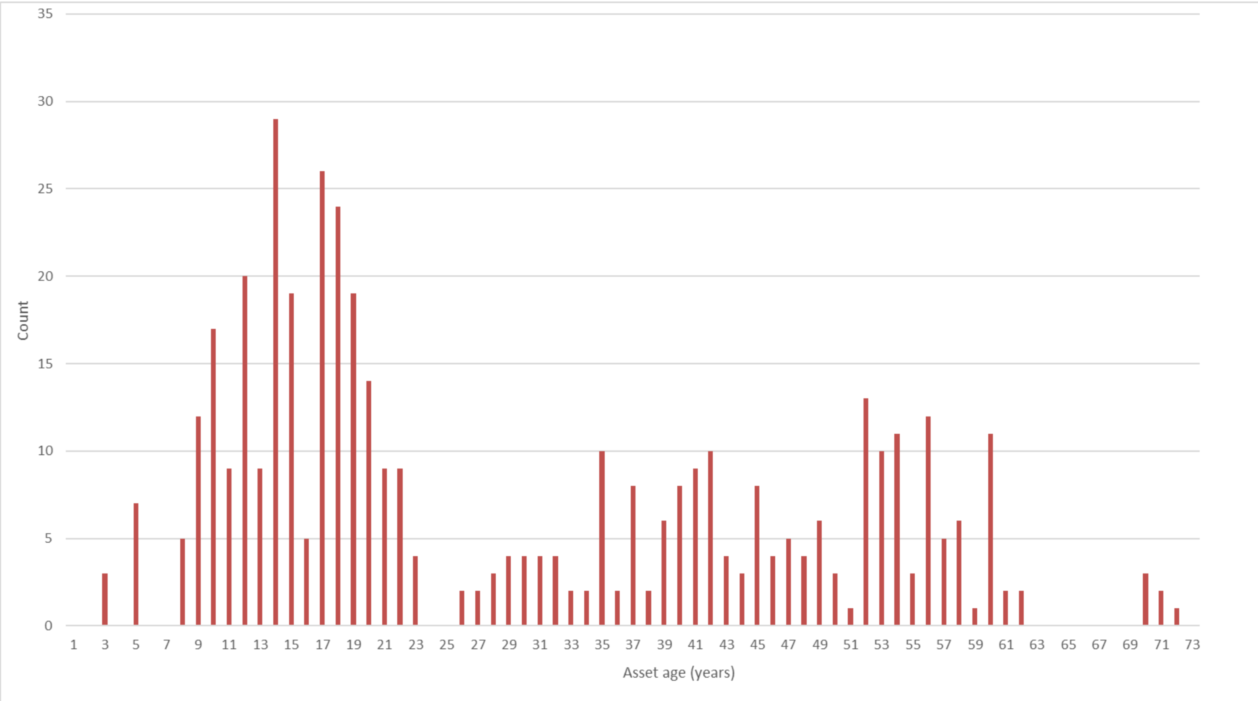
Given that generally substations have an N-1 level of redundancy amongst their power transformers, in multiple transformer substations it is unlikely that any one transformer failure will cause loss of supply to customers, and therefore there is only a very low level of reliability risk. However, where a substation contains multiple transformers of a similar advanced age and condition, the failure of one unit may trigger the failure of another or a common fault may trigger the failure of multiple units simultaneously. In a two-transformer substation for instance, the simultaneous loss of the second transformer would result in the total loss of supply from the substation and a substantial unserved energy cost (reliability risk cost). The likelihood of this is modelled by a constant which is a function of the probability of failure values across the regulator control period (RCP) for the transformer in the substation which is in the worst condition (apart from the transformer being assessed).

Where multiple transformers in a substation are of similar age and condition, they will be identified by the value assessment for replacement at the same time. The rule applied in this case is to schedule the transformer whose replacement gives the highest value for planned risk-based replacement and then to defer the second unit for reassessment prior to the next regulatory control period.

Given two transformers of advanced age, each with similar health scores, once one is replaced, the likelihood of the simultaneous failure reduces significantly and therefore the assessment being re-run for the next RCP may not recommend the risk-based replacement of the remaining aged transformer.

Figure 1 below shows the age profile of the fleet of power transformers as of calendar year 2022. Those transformers in the 55 – 70 year age cohort, in substations with only two power transformers and where both transformers are of a similar age and condition are most likely candidates for risk-based replacement due to their higher probabilities of failure and the higher reliability impacts of failure.

Figure 1 – Power transformer age profile



1.3 Options analysis

There are no credible non-network options for replacing the functionality of a power transformer given the large amount of energy which flows through them on a continual basis.

The network options available for addressing the failure risk of individual power transformers in a planned risk-based manner which is considered to be credible include retirement, refurbishment, and retirement followed by the replacement. The value model assessing each transformer for replacement. Those that are selected for replacement during the period of interest are then assessed for their ongoing value in the network and their suitability for refurbishment. If their capacity is still required and they are not suitable for refurbishment, they are scheduled for replacement. Generally, the replacement asset is a modern equivalent transformer with capacity based on the current and forecast utilisation of the asset and the available standardised transformer sizes. Occasionally an existing transformer may be relocated to provide for the replacement providing its specification and condition are suitable. An inventory of strategic spare units is kept on hand for the reactive replacement of transformers which fail unexpectedly while in service.

On this basis, and taking into account the above replacement strategy, the Predictive Analytics cost-benefit assessment identified five transformers whose net present value (NPV) of intervention is positive and reaches its maximum value in the FY25 - FY29 period. Each of these transformers also have sister transformers of similar age and condition which gives a high likelihood of simultaneous failure of two transformers with a subsequent high reliability risk. Table 1 below summarises the outcomes of this assessment. Costs are in real FY 23 terms.

Table 1 – Economic evaluation summary

No.	Transformer	Optimum replacement year (FY)	Age at optimum replacement year (years)	NPV ($M)	Replacement cost ($M)
1.	South Wollongong ZS, 33kV, No. 2	2025	58	1.71	1.63
2.	Warilla ZS, 33kV, No. 3	2025	65	1.58	1.30
3.	Port Central ZS, 33kV, No. 2	2025	56	0.98	1.63
4.	Unanderra ZS, 33kV, No. 1	2025	64	0.87	1.30
5.	Wombarra ZS, 33kV, No. 1	2025	63	0.83	1.30
Totals				**5.97**	**7.16**

1.4 Recommended option

The recommended option is the retirement and replacement of the five power transformers that are assessed as reaching their maximum positive NPV in the FY25 – FY29 period.

1.5 Budget

The total cost of the risk-based replacement works is estimated to be $7.16 million in real FY 23 terms.

The additional funding proposed for power transformers that are likely to fail in service is $8.16 million giving a total recommended funding of $15.32 million.

Table 2 below shows the proposed investment, in the forthcoming RCP, compared to the actual and forecast investment in the current regulatory period. All costs are shown in real FY23 terms.

As shown in Table 2, the proposed investment is comparable to the investment in the current regulatory period. To date there has been no material investment in reactive condition-based replacement of power transformers within the current RCP. However, a forecast has not been made of what may be required in the remainder of the period and therefore, there is potential for the investment in the current period to increase beyond the figures shown in Table 2.

Table 2 – RCP investment comparison

Investment category	Current FY20 – 24 RCP	Forecast RFY25-29 RCP
Planned risk-based	14.45	7.16
Reactive condition-based	0	8.16
Total	**14.45**	**15.32**

Table 3 below shows the range of previously approved power transformer replacement projects which make up the investments prior to the start of the FY25 – 29 regulatory period, shown in Table 2 above. Project NTS-000473 is work in progress and the investments proposed in this case for investment and the forecast reactive investment will complement these works.

Table 3 – Previous power transformer replacement projects

Project numbers	Projects
TS615 – TS618	Risk-based replacement of power transformers at Gerringong ZS, Camellia TS, Prospect ZS and Albion Park ZS
TS619, TS620	Reactive replacement of power transformer No. 1 at Minto ZS following a failure in service and the recovery from the failure of power transformer No. 2 at Dundas ZS
NTS-000473	Risk-based replacement of power transformers at Outer Harbour TS, Inner Harbour ZS, South Nowra ZS, Gerringong ZS and Blackmans Flat ZS.

2. Purpose

The purpose of this document is to seek endorsement of the case for investment (CFI) for managing the risks posed by aged power transformers throughout the network.

This CFI recommends the planned risk-based intervention for the retirement and subsequent replacement of the five identified power transformers during the FY25 – FY29 regulatory control period (RCP) and provision of additional capital for the reactive replacement of power transformers that may fail unexpectedly during the period.

It is noted that this CFI is recommending investment to be included into the portfolio risk-based asset investment planning and optimisation process during the period of FY25 – FY29.

3. Identified needs and/or opportunities

3.1 Background

Endeavour Energy's fleet of 457 power transformers in service at voltages of 132kV, 66kV and 33kV.

The transformers are in service in zone and transmission substations and customer substations and are used to transform electricity from one voltage to usually a lower voltage to allow for its distribution to customers.

Table 4 below shows the breakdown of the fleet of power transformers by voltage and standardised capacity class.

Table 4 – Power transformer fleet summary

Voltage (kV)	Capacity ranges (MVA)						Totals
	120	60	45	35	25	<=15	
132	36	42	54	2	1		135
66				34	17	14	65
33				43	139	69	251
11/22 (auto transformers)					2	4	6
Total	**36**	**42**	**54**	**79**	**159**	**87**	**457**

The current fleet of power transformers has been installed progressively as the network has expanded and been renewed over the last 60 or so years. Figure 2 shows the current age profile of the fleet of power transformers.

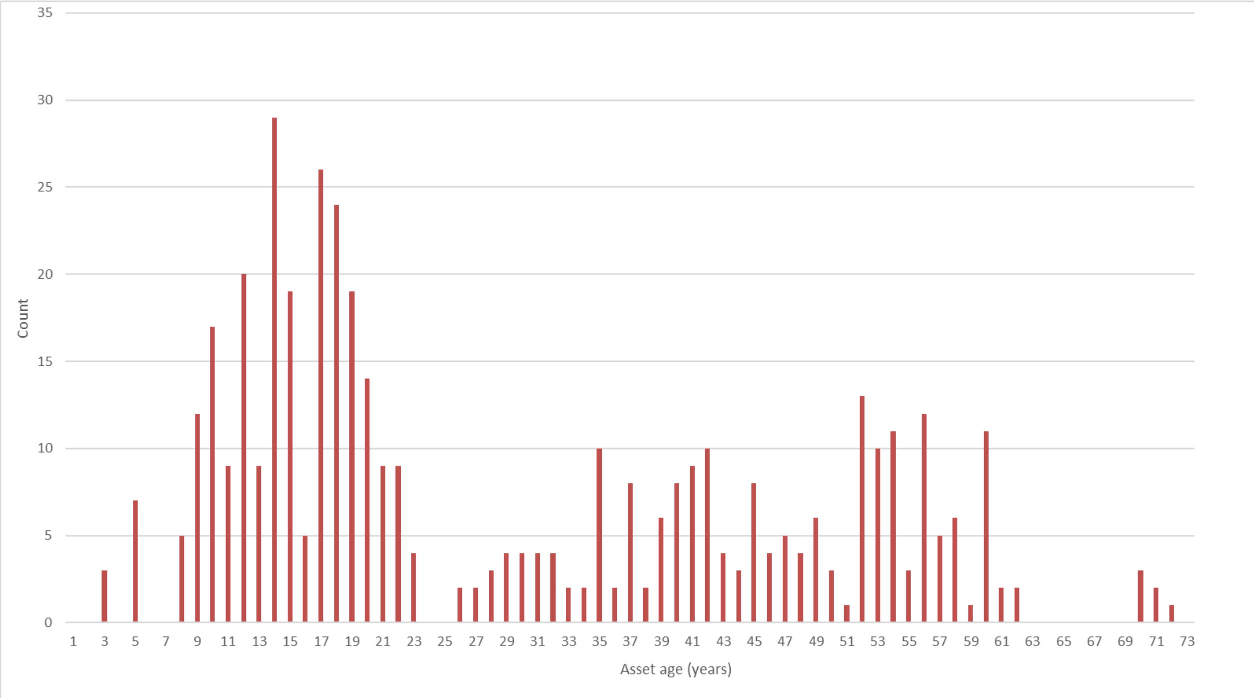
In the recent past, programs have been undertaken to replace power transformers as they reach the end of their lives. Replacements have generally been modern equivalents with the same or increased capacity (to standardised values) as required to meet the forecast demand.

A summary of the recent power transformer replacement programs is shown in Table 5 below. Project NTS-000473 is currently work in progress and the investments proposed in this case for investment and the forecast reactive investment will complement these works.

Table 5 – Previous power transformer replacement projects

Project numbers	Projects
TS615 – TS618	Risk-based replacement of power transformers at Gerringong ZS, Camellia TS, Prospect ZS and Albion Park ZS
TS619, TS620	Reactive replacement of power transformer No. 1 at Minto ZS following a failure in service and the recovery from the failure of power transformer No. 2 at Dundas ZS
NTS-000473	Risk-based replacement of power transformers at Outer Harbour TS, Inner Harbour ZS, South Nowra ZS, Gerringong ZS and Blackmans Flat ZS.

Figure 2 – Power transformer age profile



3.2 Risks and identified need

Power transformers can suffer a range of failure modes, many of which are repairable. However, the functional failures which will result in the transformer being removed from service by the operation of protection systems and will generally end the life of the transformer include:

- Breakdown of the insulation around the windings due to natural degradation over time (the paper insulation strength deteriorates over time in the presence of moisture and heat);
- Breakdown of the insulation around the windings due to movement of the windings caused by the passage of fault current;
- Mechanical or insulation failure in the tap-changer;
- Non-repairable failures of the secondary systems built into the transformer;
- Loss of integrity of the tank (usually due to corrosion damage) resulting in the loss of insulting oil.

Functional failures result in consequences which may include:

- Loss of supply to customers, depending on the type and topology of the substation;
- A financial impact of switching around the failed asset to restore or secure supply to customers, and then changing the transformer out for a unit from the essential spares pool; and

- Reactive capital costs – the cost of replacing the failed transformer (or the unit taken from the spares pool) in a reactive manner.

The safety and environmental risks associated with failure are generally very low and therefore risk-based replacement is driven by the likelihood of causing loss of supply to customers and the value of that unserved energy.

Given that generally substations have an N-1 level of redundancy for their power transformers, in multiple transformer substations, it is unlikely that any one transformer failure will cause loss of supply to customers, and therefore there is only a very low level of reliability risk. However, where a substation contains multiple transformers of a similar advanced age and condition, the failure of one unit may trigger the failure of another or a common fault may trigger the failure of multiple units simultaneously. In a two-transformer substation for instance, the simultaneous loss of the second transformer would result in the total loss of supply from the substation and a substantial unserved energy cost (reliability risk cost). The likelihood of this is modelled by a constant which is a function of the probability of failure values across the RCP for the transformer in the substation which is in the worst condition (apart from the transformer being assessed).

Where multiple transformers in a substation are of similar age and condition, they will be identified by the value assessment for replacement at the same time. The rule applied in this case is to schedule the transformer whose replacement gives the highest value for planned risk-based replacement and then to defer the second unit for reassessment prior to the next regulatory control period[1].

Given two transformers of advanced age, each with similar health scores, once one is replaced, the likelihood of the simultaneous failure reduces significantly and therefore the assessment being re-run for the next RCP may not recommend the risk-based replacement of the second aged transformer.

The assessment of the value of intervention is performed using the relative probability of failure (modified probability density function) method[2] as implemented in the Copperleaf Predictive Analytics application. Transformers are identified for risk-based retirement and replacement when the net present value (NPV) of the intervention reaches its maximum value.

Replacement transformers are generally new units. Spare units are kept on hand to replace transformers which fail unexpectedly whilst in service.

This CFI applies the Common Network Asset Indices Methodology (CNAIM) methodology [1] to determine the health of each power transformer and its current probability of failure and forecast into the future.

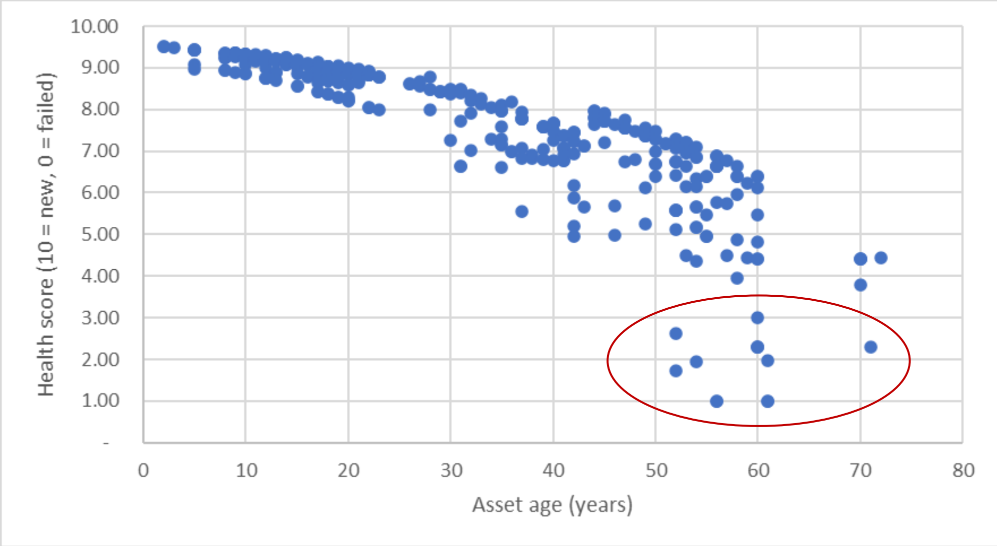
Typically, the health score is a function of age, but also adjusted for oil and signature test results, external condition of the transformer, loading history, design and geographic location.

Figure 3 below shows the health score for each in-service transformer against their age. The assets most likely to be selected for risk-based replacement are those with the low health scores as circled in the figure.

[1] There is risk when replacing only one of a pair of old transformers with a modern equivalent of standardised rating, that the old and the new transformers will not share load equitably due to differing impedances which can reduce the firm capacity of a three-transformer substation. Network Planning have confirmed that in the cases proposed in this CFI, the reduction in firm capacity is not material and therefore does not affect the recommendations.

[2] The probability an asset that exists today will fail in each future year. The sum of relative PoF over all future years is 100%. May also be termed "modified PDF". Applicable to non-repairable asset failures which signal the end of the asset's life.

Figure 3 - Transformer health score versus age



4. Consequences of nil intervention

4.1 Consequences of nil capital intervention

The nil intervention case involves not carrying out any capital works. Therefore, power transformers would be operated until they experienced a functional failure and then retired and not replaced if they could not be returned to service after a post-fault maintenance intervention.

The consequences of this would include the gradual reduction of transformation capacity in the network resulting over time in widespread and sustained loss of supply to our customers as network capacity reduced to below existing demand levels. This would incur significant costs based on the prevailing value of customer reliability.

This is not considered to be a tenable situation as it directly undermines service levels to customers, Endeavour Energy's business model and the principles of providing safe, sustainable and reliable energy that we have committed to in the Energy Charter [2].

On this basis, the reactive replacement of power transformer which fail will be undertaken, subject to an assessment of the ongoing need for the asset, and the nil intervention case will not be considered further in this CFI.

4.2 Counterfactual (run to failure)

The counterfactual scenario includes operating power transformers until they suffer a non-repairable functional failure after which they are replaced with a modern equivalent asset, providing the service provided by the transformer is still required. Nil risk-based capital intervention is carried out.

5. Options considered

5.1 Non-network options

Based on previous market engagement for projects with transformer replacement elements, there do not appear to be any credible non-network solutions which could replace the service provided by the power transformers at the sites being reviewed or could mitigate the risks presented by the assets and therefore network options have been considered to address the identified risk.[3],

In some situations where the transformers are particularly lightly loaded, there may be alternatives to replacement and these are being considered on a case-by-case basis.

5.2 Credible network options

A number of credible options are available for consideration on a case-by-case basis taking into account the risk associated with the individual transformer as well as the condition of and risks posed by the other transformers operating in parallel in the substation. The options available are summarised in Table 6 below.

Table 6 – Credible intervention options

Option	Scenario	Works Description
1	Asset retired/site reconfigured	This option involves removing the asset from the network once the risk associated with the site has been managed.
2	Maintain/refurbish the transformer	A review to ensure no maintenance/refurbishment options are available for the unit that may defer the assets replacement needs and/or reduce the assets likelihood or consequence of failure.
3	Replace the transformer	Review the condition of the transformers at the site and determine the transformer configuration which is appropriate for future needs. Replace the existing transformer with a new unit and/or establish a plan to achieve the revised configuration.

The initial pass of value assessment which informs this CFI considers only Option 3, focussed on the modern equivalent like for like replacement of each transformer in the fleet.

Each transformer identified for replacement is then assessed for feasibility of Option 1 (retirement without replacement) and Option 2 (refurbishment) being applied.

5.2.1 Power transformer replacement

Under the Option 3, the intervention includes the replacement of the selected power transformers in a planned manner to allow for the retirement of the existing transformer.

Generally new transformers are purchased for planned replacements and the removed transformer is scrapped. Replacement transformers may also be relocated from other locations in the network where surplus and when configuration, capacity and condition are suitable.

The replacement transformers are generally like for like modern equivalent with the same vector arrangement and physical arrangement of bushings and/or cable boxes as the existing transformers but with standardised capacities.

Replacement costs include:

- Removal and disposal of the existing transformer;
- Supply and installation of the new transformer;
- An average allowance for replacement of secondary voltage cabling; and
- An average allowance for modifications to the oil containment bund.

[3] Marayong Zone Substation renewal RIT-D, Sussex Inlet Zone Substation renewal RIT-D screening report for non-network options contained similar energy and demand supply parameters as the transformer retirement/replacement decisions being investigated in this case for investment. Each received nil non-network solution proposals from the market.

Estimated costs for Endeavour Energy's eight standard transformers are shown in Table 7 below. All costs are in real FY23 terms.

Table 7 – Power transformer replacement costs

Transformer type	Estimated replacement cost ($M)
33/11kV 15MVA Low Noise	1.30
33/11kV 25MVA Low Noise	1.63
33/11kV 35MVA Low Noise	1.83
132/11kV 45MVA Low Noise	2.80
132/33/11kV 60MVA	2.98
132/66/11kV 60MVA	3.03
132/33/11kV 120MVA	3.94
132/66/11kV 120MVA	3.96

5.3 Economic evaluation

The economic evaluation is performed using the relative probability of failure (modified probability density function) method as noted in 3.2. This methodology is implemented in the Copperleaf Predictive Analytics application which identifies the optimal time for intervention (in this case retirement followed by replacement) when the NPV of the present value of the benefits provided by the intervention in terms of reduced or deferred failure risk, less the present value of the intervention costs, is positive and reaches its maximum value. Assets whose assessment indicates a run-to-failure[4] approach as providing the greatest value are characterised by an NPV of intervention which commences with a negative value which increases and converges to zero over time.

Five power transformers whose NPV of replacement reaches a maximum value during the FY25 – FY29 period have been identified. The NPV of the individual asset replacements ranges from $0.83 million to $1.71 million with an average value of $1.29 million. The cost of the proposed program in real FY 23 terms is $7.16 million.

Table 8 provides detail of the five transformers identified for planned risk-based replacement and Table 9 shows the results of the economic evaluation.

[4] In practice, transformers are rarely intentionally left to fail in service but are programmed for replacement when their test results indicate imminent failure

Table 8 – Option 3 transformer details

Transformer	Equipment Number	Voltage (kV)	Capacity (MVA)	Manufacturer	Current age	Current health score (10 = new)
South Wollongong ZS, 33kV, No. 2	175127	33/11	19	Standard Waygood	56	3.72
Warilla ZS, 33kV, No. 3	175138	33/11	10	British General Electric	60	4.22
Port Central ZS, 33kV, No. 2	175124	33/11	19	Brush	54	5.07
Unanderra ZS, 33kV, No. 1	175130	33/11	12.5	British General Electric	60	4.22
Wombarra ZS, 33kV, No. 1	175074	33/11	5	Standard Waygood	61	3.72

Each intervention in the proposed program provides a positive NPV which also reaches its maximum value during the FY25 – FY29 period and therefore provides the highest value compared to the counterfactual approach of allowing the transformers to fail in service and to other timings for the interventions.

Table 9 – Option 3 Economic evaluation summary

Transformer	Optimum intervention year	Age at intervention (years)	PV of reliability risk benefit ($M)	PV of financial risk benefit ($M)	PV of investment ($M)	NPV ($M)
South Wollongong ZS, 33kV, No. 2	2025	58	1.11	1.81	1.20	1.71
Warilla ZS, 33kV, No. 3	2025	65	1.27	1.34	1.02	1.58
Port Central ZS, 33kV, No. 2	2025	56	0.92	1.44	1.38	0.98
Unanderra ZS, 33kV, No. 1	2025	62	0.62	1.27	1.02	0.87
Wombarra ZS, 33kV, No. 1	2025	63	0.36	1.44	0.96	0.83
Totals			**4.27**	**7.28**	**5.58**	**5.97**

5.4 Economic evaluation assumptions

The CNAIM methodology [1] develops an annual probability of failure versus age function for each transformer based on the inputs of:

- Age;
- Type of transformer
- Location;
- Duty;
- Oil test, winding signature tests and electrical test results; and
- Inspection results

In this CFI, the transformer and the tap-changer are considered as one unit.

Other inputs to the economic evaluation include:

- The reliability consequences of failure - based on the number of transformers in the substation, the substation maximum demand and average load factor, the value of customer reliability applicable to the substation and the likelihood of redundancy not being available due to maintenance or a fault in the network and the likelihood of simultaneous failure of a second transformer in the substation;

- The financial consequences of failure – based on the replacement cost of the transformer, additional reactive response and investigation works, and the probability of replacement of a second transformer.

Refer Appendix 1 for further detail of input data, assumptions and methodology.

Due to the general availability of N-1 supply security, many transformers will never become economical to replace on a risk basis and will therefore continue to be operated until they suffer a non-repairable functional failure.

The value assessment model identifies aged transformers in poor condition in substations where the other transformers are also aged and poor condition giving a high probability of simultaneous failure against a low replacement cost and reasonable value of unserved energy.

On this basis, five transformers have been identified for risk-based replacement over the next RCP. Other transformers may fail in service and require replacement in a reactive manner.

5.5 Reactive condition-based replacements

Figure 4 and Table 10 below show the forecast of reactive condition-based transformer replacement investment expected for the RCP. The forecast transitions from the current annual rate of failures of 0.4. All costs are in real FY 23 terms.

Figure 4 – Forecast trend of reactive condition-based power transformer replacements

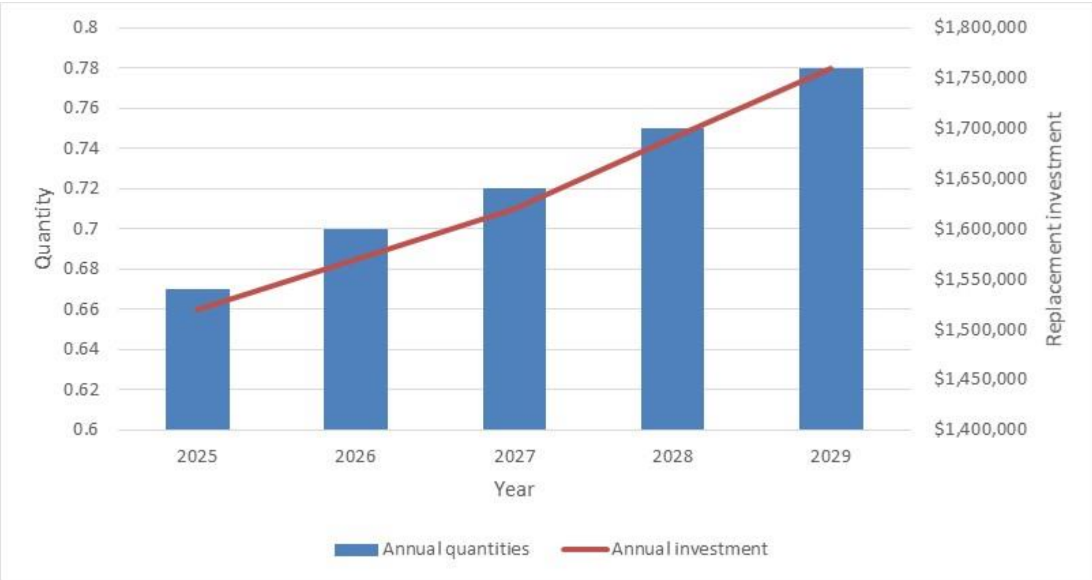


Table 10 – Forecast reactive transformer replacement investment

Period	Reactive transformer failure volume (units)	Estimated reactive replacement investment ($M)
FY25	0.67	1.52
FY26	0.70	1.57
FY27	0.72	1.62
FY28	0.75	1.69
FY29	0.78	1.76
Total	**3.62**	**8.16**

5.6 Scenario assessment

A scenario assessment has been carried out on the various elements of the risk and cost assumptions used in the economic analysis in order to test the robustness of the evaluation.

Three scenarios have been assessed:

- Scenario 1 – lower benefits and higher capital costs;
- Scenario 2 - represents the most likely central case based on estimated or established values;
- Scenario 3 - higher benefits with lower capital costs.

The values for each of the variables used for each scenario are shown in Table 11 below.

Table 11 – Summary of scenarios investigated

Variable	Commentary	Scenario 1 – low benefits, high costs	Scenario 2 – central values	Scenario 3 – higher benefits, lower costs
Simultaneous failure constant * PoF	Estimated value - test impact of a variation	75% of estimated value (6)	Estimated value (8)	125% of estimated value (10)
Probability of failure	Calculated by CNAIM model. Leave as calculated	CNAIM calculated PoF	CNAIM calculated PoF	CNAIM calculated PoF
Capital cost	Averaged values - test impact of a variation	125% of estimated average network capital costs	Estimated average network capital costs	75% of estimated average network capital costs
Value of customer (VCR)	Stable values calculated values - leave as calculated.	Assessed values	Assessed values	Assessed values
Outage duration due to failure	Estimated average values - test impact a variation.	75% of estimated average values (2.25 hours)	Assessed values (3 hours)	125% of estimated average values (3.75 hours)

The impact on the proposed planned risk-based replacement program for each scenario is shown in Table 12 below.

Table 12 – Proposed risk-based replacement volumes for each scenario

Identified transformer replacements	Scenario 1 – optimum replacement year	Scenario 2 – optimum replacement year	Scenario 3 - optimum replacement year
South Wollongong ZS, 33kV, No. 2	2025	2025	2025
Warilla ZS, 33kV, No. 3	2025	2025	2025
Unanderra ZS, 33kV, No. 1	2025	2025	2025
Wombarra ZS, 33kV, No. 1	2025	2025	2025
Port Central ZS, 33kV, No. 2	2030	2025	2025
Sussex Inlet ZS, 33kV, No. 2	2040	2034	2028
Hartley Vale ZS, 66kV, No. 2	2046	2037	2027
Total investment in RCP ($M)	**5.53**	**7.16**	**9.76**

As shown in Table 12, the low benefits boundary scenario proposes four risk-based replacements during the regulatory period and the high-benefits scenario proposes seven. The central scenario proposes five replacements. The relatively small spread of recommended replacements across the boundary scenarios indicates that the economic evaluation is not particularly sensitive to the subjective variables applied. On this basis it is considered that works proposed in the central case represent an appropriate level of risk-based investment to serve as a test for the economic assessment methodology through the upcoming RCP.

5.7 Test for alternative network options

Table 13 below summarises the test for replacement for each of the transformers proposed for risk-based replacement[5]. Refer Appendix 3 for further detail.

[5] A range of other transformers were also identified for replacement during the period. These include other units at each of the five identified substations and the transformer at the Visy Paper customer substation. The alternate transformers at each of the five substations have been removed from the results following the strategy discussed in 3.2. The transformer at the Visy Paper is reasonably young at 17 years and is in good condition. However, as it is a single transformer substation, there are very high CoF and hence a tendency to signal the transformer for replacement early. This is typical of single transformer customer substations. However, since the customer is only paying for a supply without redundancy, the model needs to be adjusted to take this into account by reducing the CoF (reducing the VCR value applied), in future cases for investment.

Table 13 – Test for alternative network options

Proposed replacements	Equipment number	Test for Option 1 - retirement	Test for Option 2 - refurbishment	Conclusion
South Wollongong ZS, 33kV, No. 2	175127	Planning confirm 25MVA replacement capacity required	Age of 56 year is past the economical age for refurbishment	Replace with standardised 33/11kV 25MVA low noise TX
Warilla ZS, 33kV, No. 3	175138	Planning confirm 15MVA replacement capacity required	Age of 61 years is past the economical age for refurbishment	Replace with standardised 33/11kV 15MVA low noise TX
Unanderra ZS, 33kV, No. 1	175130	Planning confirm 15MVA replacement capacity required	Age of 60 years is past the economical age for refurbishment	Replace with standardised 33/11kV 15MVA low noise TX
Wombarra ZS, 33kV, No. 1	175074	Planning confirm 15MVA replacement capacity required	Age of 61 years is past the economical age for refurbishment	Replace with standardised 33/11kV 15MVA low noise TX
Port Central ZS, 33kV, No. 2	175124	Planning confirm 25MVA replacement capacity required	Age of 54 year is past the economical age for refurbishment	Replace with standardised 33/11kV 25MVA low noise TX

6. Preferred option details

6.1 FY25 – FY29 scope and timing

The preferred program for optimisation includes the replacement of five power transformers during FY25 – FY29.

The overall cost of the proposed program is estimated to be $7.16 million.

6.2 Investment summary

6.2.1 Planned risk-based works

A summary of the investment proposed to be submitted for portfolio optimisation is shown in Table 14 below.

Table 14 – Planned risk-based investment

Transformer	Equipment number	Replacement unit ($M)	Replacement cost ($M)
South Wollongong ZS, 33kV, No. 2	175127	33/11kV 25MVA	1.63
Warilla ZS, 33kV, No. 2	175138	33/11kV 15MVA	1.30
Unanderra ZS, 33kV, No. 1	175130	33/11kV 15MVA	1.30
Wombarra ZS, 33kV, No. 1	175074	33/11kV 15MVA	1.30
Port Central ZS, 33kV, No. 2	175124	33/11kV 25MVA	1.63
Total			**7.16**

Table 15 below shows the forecast reactive replacement investment while Table 16 compares the forecast risk-based and condition-based investment in the forthcoming RCP with the actual and forecast investment in the current regulatory period. All costs are shown in real FY23 terms.

As shown in Table 15, the proposed investment is comparable to the investment in the current regulatory period. To date there has been no material investment in reactive condition-based replacement of power transformers within the current RCP. However, a forecast has not been made of what may be required in the remainder of the period and therefore, there is potential for the investment in the current period to increase beyond the figures shown in Table 16.

Table 15 – Reactive investment forecast

Financial year	Reactive investment forecast ($M)
2025	1.520
2026	1.570
2027	1.620
2028	1.690
2029	1.760
Totals	**8.160**

Table 16 – RCP investment comparison

Investment category	Current FY20 – 24 RCP	Forecast RFY25-29 RCP
Planned risk-based	14.45	7.16
Reactive condition-based	0	8.16
Total	**14.45**	**15.32**

6.3 Project scope for planned works

The proposed scope for each planned transformer replacement is generally as outlined below:

- Order and purchase replacement transformer with the same bushing/cable box arrangement as the existing transformer as per existing supply contracts;
- Decommission and remove the existing transformer;
- Carry out any bund modification and transformer modification or replacement works as required;
- Install, test and commission replacement transformer;
- Update asset information in SAP;
- Dispose of removed equipment. Retain any equipment and/or parts for spares as specified by the Region.

6.4 Project scope for reactive replacement works

The proposed scope for each reactive transformer replacement is generally as outlined below:

- Decommission and remove existing transformer;
- Carry out any bund modification and transformer modification or replacement works as required;
- Install, test and commission replacement transformer from essential spares stores;
- Update asset information in SAP;
- Dispose of removed equipment. Retain any equipment and/or parts for spares as specified by the Region;
- Order replacement transformer for replenishing the essential spares stock.

7. Regulatory investment test

Within this recommended program of works, each asset has been assessed individually for the risk it presents. Furthermore, this is an ongoing program with no material change proposed across the asset type and with investment in the forthcoming RCP forecast to be similar to the investment in the current period. The highest cost credible option at each site falls below the threshold for application of the Regulatory Investment Test for Distribution (RIT-D) (currently $6.0 million) and likewise, the change in investment in the program from the current to the next RCP is less than $6.0 million. Therefore, the RIT-D is considered to not be applicable to this program.

8. Recommendation

It is recommended that the planned risk-based replacement of five power transformer where the intervention provides a maximum and positive NPV in the period of FY25 – FY29, at an estimated cost of $7.16 million, as outlined as Option 3 in this case for investment, be included in the PIP and to proceed to the investment portfolio optimisation stage.

It is further proposed that an allowance for an additional $8.16 million be made within the FY25 - FY29 period for the reactive replacement of power transformer that may fail unexpectedly.

9. Attachments

Appendix 1 – Summary of key risk assessment variables and assumptions

Appendix 2 – Scenario assessment details

Appendix 3 – Replacement assessment check

10. References

[1] “DNO Common Network Asset Indices Methodology. Health and Criticality - Version 2.0 Draft,” UK Ofgem Safety, Resilience and Reliability Working Group, 2020.

[2] “The Energy Charter,” theenergycharter.com.au, January 2019.

[3] Endeavour Energy, “Summer Demand Forecast 2022 - 2031,” Network Demand Forecasting Section, 2021.

[4] “Winter Demand Forecast 2021-2030,” Endeavour Energy, 2021.

Appendix 1 – Summary of key risk assessment variables and assumptions

General variables and assumptions

Parameter	Value	Description/justification	Source/assumptions
Population	457	Number of power transformers in service in Endeavour Energy's network	Ellipse database. Current to October 2021. Asset type CB.
Annual conditional failures	0.2	Dundas ZS 66kV TX 2 was retired in 2017 after conditional of tap-changer assessed as at imminent risk of failure.	One actual incident over five years
Annual functional failures	0.2	One functional failure (Minto ZS 66kV TX 1) that resulted in the power transformers being retired and replaced has occurred in the last five years – giving a very nominal rate of failure of 0.2 pa	One actual incident over five years
Discount rate (WACC)	3.26%	Weighted average cost of capital for EE	Regulated rate. Applied to all risk and investment values used in the cost-benefit assessment.
Base year of investment	FY23	All investments for budgeting purposes are expressed in real FY23 dollars	
Calculation horizon	100 years	The timeframe over which the cost-benefit analysis is performed in Copperleaf Predictive Analytics – to take into account the remaining life of the existing asset and that of the replacement asset	
Maintenance costs	Varies	All transformers incur routine inspection and preventative maintenance costs but cost of ownership is differentiated by non-routine maintenance such as "Fault and Emergency" and "Condition Based" maintenance. Maintenance costs are generally not material however, and in this CFI, to simplify the assessment, maintenance costs have been omitted.	N/A
Planned intervention costs – transformer replacement	All units	Planning cost estimates including: - supply of a standardised transformer from the Company's period contracts; - installation and commissioning; - an allowance for project management; - an average allowance for bund modification; - an average allowance for secondary side cable replacement costs.	All values provided by Substation Design in FY21 based on previous projects, indexed at 2.5% pa to $FY23. Tested against recent offers (supply only) being received from the market by Engineering Delivery Manager
	$1,296,000	33/11kV 15MVA Low Noise	
	$1,630,000	33/11kV 25MVA Low Noise	
	$1,834,000	33/11kV 35MVA Low Noise	
	$2,786,000	132/11kV 45MVA Low Noise	
	$2,975,000	132/33/11kV 60MVA	
	$3,025,000	132/66/11kV 60MVA	
	$3,940,000	132/33/11kV 120MVA	
	$3,960,000	132/66/11kV 120MVA	

Parameter	Value	Description/justification	Source/assumptions
Reactive intervention	All	As for planned intervention. The additional costs associated with switching, securing a firm supply, removing and disposing of the failed transformer and investigation, are covered by the financial CoF.	As per planned intervention. Financial CoF based on estimates of the cost of response to previous failures.
Failure modes - Conditional	Various	Refer Asset Class Plan	Refer asset class plan
Failure modes - functional	Various	Refer Asset Class Plan	Refer asset class plan
Asset age	Specific to each transformer	Calendar age based on the transformer in-service date compared to the year of assessment (2023) Youngest transformer age = 2 years Oldest transformer age = 72 years	Data from Ellipse.

Probability of failure parameters – CNAIM methodology

CNAIM model inputs	Value	Description/justification	Source/assumptions
Basic transformer data	Various	Transformer equipment number, capacity and voltage, type, in-service date	Ellipse
Transformer location	Geographic information for each transformer	Geographic information for each transformer which positions the transformers near more corrosive environments such as thew coats line	ESRI geographic database and GIS database
Oil tests	Specific to each transformer	Oil test results information for each transformer is read and modifies the PoF	Test results from spreadsheets on shared drive G:\Oildata
DP tests	Specific to each transformer	Winding paper insulation degree of polymerisation test results. Used to modify the PoF for each transformer	Test results from spreadsheets on shared drive G:\Oildata
Regenerated oil	Date specific to each transformer	Date of the last oil regeneration if applicable. None has been carried out in the last 10 years and therefore this is not material	G:\Oildata
Replaced oil	Date specific to each transformer	Date of the last oil replacement if applicable.	G:\Oildata
Tap-changer	Data specific to each transformer	Basic data for each tap-changer. Tap-changers and main transformer tanks are treated as the one asset in Endeavour's implementation of the CNAIM model.	G:\Oildata
Refurbishment history	Date specific to each transformer	Date of the last refurbishment activity if applicable.	G:\Oildata
Normal expected life	50 years 60 years	Default CNAIM values based on the voltage and type of transformer and the era win which it was constructed	Transformer PoF model lookup tables
Transformer classification	Specific to transformer type	Translation of EE's transformer types to CNAIM standard categories	Transformer PoF model lookup tables
Altitude factor	Factor to adjust the PoF based ion altitude of the installation		Not used
Corrosion factor	Factor which adjusts the PoF based on the corrosivity of the environment around the transformer	Based on UK data. Needs developing for the local conditions	Not used

CNAIM model inputs	Value	Description/justification	Source/assumptions
Default environment	Specific to transformer type	Default values for the range of standard transformer categories as input variables for the CNAIM model	Transformer PoF model lookup tables
Duty factor	Specific to transformer type	Default values for the range of standard transformer categories as input variables for the CNAIM model	Transformer PoF model lookup tables
Observed condition inputs	Specific to transformer type	Default values for the range of standard transformer categories as input variables for the CNAIM model	Transformer PoF model lookup tables
Main transformer	‘	‘	‘
Tank condition	‘	‘	‘
Coolers condition	‘	‘	‘
Bushings condition	‘	‘	‘
Kiosk condition	‘	‘	‘
Cable box condition	‘	‘	‘
Tap-changer	‘	‘	‘
External condition	‘	‘	‘
Internal condition	‘	‘	‘
Drive mechanism condition	‘	‘	‘
Condition of selector and diverter contacts	‘	‘	‘
Condition of selector and diverter braids	‘	‘	‘
Measured condition inputs	‘	‘	‘
Partial discharge	‘	‘	‘
Temperature readings	‘	‘	‘
Tapchanger partial discharge	‘	‘	‘
Oil test results factor	‘	‘	‘
Oil moisture content	‘	‘	‘
Oil acidity	‘	‘	‘
Oil DGA results factor	‘	‘	‘
FFA test results factor	‘	‘	‘
Reliability Factor	0.6 – 1.5	Manually applied factor which impacts the calculation of PoF. Based on wider sources of knowledge of the condition and performance of the transformer. Generally default value of 1.0 has been used. 0.8 applied to North Wollongong ZS PX to reflect the likely improvement made by refurbishment works carried out in 2012	Assumption that refurbishment of PX at North Wollongong in 2012 will have an impact on the current PoF
Interventions	Various	Logging assets which are already approved for replacement (for exclusion from the general PoF modelling). Also includes values for the reliability factor where appropriate.	

CNAIM model inputs	Value	Description/justification	Source/assumptions
CoF inputs	Various	Spreadsheet which contains the input information such as Basic financial CoF, replacement costs etc	Estimation and cost estimate data
Substation VCR values	Specific to each substation	Value of customer reliability for an occasional short-term outage calculated for each substation based on customer mix and standard VCR values provided by the AER	Network Planning Manager – published VCR values for each substation (Endeavour Energy specific VCRs.xlsx 20220524)

Safety risk inputs

Parameter	Value	Description/ justification	Source/assumptions
			Not material to the assessment and therefore assumed to be nil. Experience from previous transformer failures and industry experience.

Bushfire risk inputs

Parameter	Value	Description/ justification	Source/assumptions
			Nil for power transformers. All effects are contained within the substation boundaries. Experience from previous transformer failures and industry experience.

Environmental risk inputs

Parameter	Value	Description/justification	Source/assumptions
Oil leaks	Nil	Leaks and or loss of oil from transformer failure.	All transformers are bunded and any oil spill from previous failures has been captured in the bund.

Reliability risk inputs

Parameter	Value	Description/justification	Source/assumptions
Loss of supply to customers - LoC	1% generally 100% for single transformer substation	1% generalised likelihood of loss of load when N-1 supply security is available	RisCAT - 1% likelihood the alternate supply path will not be available due to maintenance, or failure.
Load impacted	Specific to each substation	The summer maximum demand of the substation at 50% probability of exceedance	2022 Summer Maximum Demand data (note – an improvement would be to assess both summer and winter peaks and take an average for this assessment)
Load factor	70%	Load assumed to be lost is 70% of the summer maximum demand value for the supplied substation(s)	Generalised load factor developed by Protection Manager based on a study of network faults.
VCR	Specific to each substation/switching station	Value of customer reliability for an occasional short-term outage	Specific values for each substation/switching station calculated by Network Planning based on values published by the AER
Power factor	0.95	Worst case value – to scale demand from MVA to MW for application of VCR	A minimum value which reduces the value of potential unserved energy. Generally zone substation power factor is 0.98 or better

Parameter	Value	Description/justification	Source/assumptions
Duration of interruption	3 hours	3 hours assumed interruption until alternate arrangements are made for supply through switching the network	A generalised value based on a range of outages of transmission assets. Assumes off-loading to reinstate supply through a combination of SCADA and manual switching of disconnectors on site and distribution switches in the field as appropriate
Coincidental failure factor	8	Utilises the PoF of other transformers in the same substation to assess the likelihood of having a simultaneous failure of the second transformer (either due to the same through-fault stresses, or due to the fault in one TX stressing the other TX) The highest PoF of the other TXs is taken at the end of the RCP and a constant applied to it to give a reasonable and consistent likelihood of two failures. The consequence is loss of 100% of supply in two transformer substations and 50% in three-transformer substations. This factor also adds the costs of replacing the second transformer to the Financial risk value of the transformer in question.	This factor has a material impact on the value model results and can shift transformers from run-to-failure to risk-based replacement. The constant applied is based on an estimation to give a realistic volume of risk-based replacements which aligns with the Repex model and SME expectations. The base value of 8 applied gives reasonable looking results which will be tested against the reactive investment demands leading up to and through the RCP.

Financial risk inputs

Parameter	Value	Description/justification	Source/assumptions
Financial general - CoC	$40,000	Switching to restore supply/supply security, clean-up, any temporary diversion works, investigation, additional removal and disposal of the failed transformer over and above what is included in a planned replacement	Estimate, based on typical clean-up and investigation costs
Financial general - LoC	100%	Likelihood of general financial risks being realised on failure	
Financial – coincidental failure	PoF	This value is a function of the PoF of other transformers in the same substation and considers the costs of replacing a second transformer in a reactive manner if that unit should fail at the same time as the first unit (due to being of the same age and condition as the unit being assessed)	As for the Coincidental failure factor
Reactive replacement costs	Varies	Reactive replacement costs generally equal planned replacement costs	Estimate based on experience of past transformer failures. A replacement transformer is provided free of charge from the Essential Spares store and then the spare unit is replaced and the costs of the replacement charged to the failed transformer replacement project.

File names and locations

File function	Type of file	Filename	Location
FME workflow	FME	TransformerPOFRev6.6.jc.fmw	C:\Users\...\Endeavour Energy\Asset Performance - General\Asset Investment\1. Asset Summaries\(PX) Power TXs\Transformer PoF Model
Inputs to the FME workflow	xlsx	Various	C:\Users\...\Endeavour Energy\Asset Performance - General\Asset Investment\1. Asset Summaries\(PX) Power TXs\Transformer PoF Model\Inputs
Outputs from the FME workflow	xlsx, csv	Various	C:\Users\...\Endeavour Energy\Asset Performance - General\Asset Investment\1. Asset Summaries\(PX) Power TXs\Transformer PoF Model\Output

File function	Type of file	Filename	Location
Assets file for loading to PA	xlsx	"PX Assets..." Data Table	C:\Users\...\Endeavour Energy\Asset Performance - General\Asset Investment\3. C55 Production (Master Copies)\4. PA - Assets\PX Three source spreadsheets used to create the three scenarios modelled in PA. These are copied to PA – Assets input spreadsheet. Note that only one set of asset scan be present in PA at a time. C:\Users\...\Endeavour Energy\Asset Performance - General\Asset Investment\1. Asset Summaries\(PX) Power TXs\Transformer PoF Model\Output: Low benefits high costs – "PX Assets_202210191422.xlsx" Central case - "PX Assets_202210191424.xlsx" High benefits, low costs – "PX Assets_202210191431.xlsx" C:\Users\...\Endeavour Energy\Asset Performance - General\Asset Investment\3. C55 Production (Master Copies)\3. PA - Data Table
Results from PA (brings together all the data and charts used in the CFI)	xlsx	PA strategy - Power TX, FY25, r4.0 20221017a.xlsx	C:\Users\...\Endeavour Energy\Asset Performance - General\Asset Investment\1. Asset Summaries\(PX) Power TXs\1. FY25\2. PA reports
Case for investment	docx	Power transformer risk-based value assessment CFI FY25 r0.2.docx	C:\Users\...\Endeavour Energy\Asset Performance - General\Asset Investment\1. Asset Summaries\(PX) Power TXs\1. FY25\1. CFI

Appendix 2 – Scenario assessment details

The value model is sensitive to the condition assessment for each transformer and to the assessment of the likelihood of simultaneous failure of another aged transformer in the substation. Each of these models contain a range of assumptions and associated uncertainties. The CNAIM model is a credible approach developed jointly by the UK regulator and the distribution network service providers in that jurisdiction. However, it relies on the availability of quality transformer condition data for its inputs and where that is not available, makes assumptions based on the age of the transformer and its location. Endeavour Energy's transformer data is reasonable but there are gaps which inevitably result in fallback to the assumed values in a range of cases.

The likelihood of simultaneous failure of a second transformer in the same substation has a direct impact on the reliability consequence of failure and on the financial consequence of failure (for the cost of replacing a second transformer in the substation besides the unit actually being assessed). This estimation is based on the probability of failure of each transformer (developed by the CNAIM methodology) scaled by a constant to give results that appear reasonable and gives consistency across the fleet of transformers. The constant has been developed and applied in a simple manner for this case for investment and there is scope for further developing the methodology in subsequent assessments, after observation of the rate of transformer failure in service through the forthcoming regulatory period.

This variable has a material impact on the value and hence optimal timing of risk-based replacement.

Given the empirical nature of the constant and the material impact it has on the value assessment, scenarios have been tested with a range of values. The transformer replacement costs and also the duration of the interruptions to customers which may eventuate from a transformer failure also materially impact on the value assessment and therefore a range of values for these variables have also been included in the scenarios assessed.

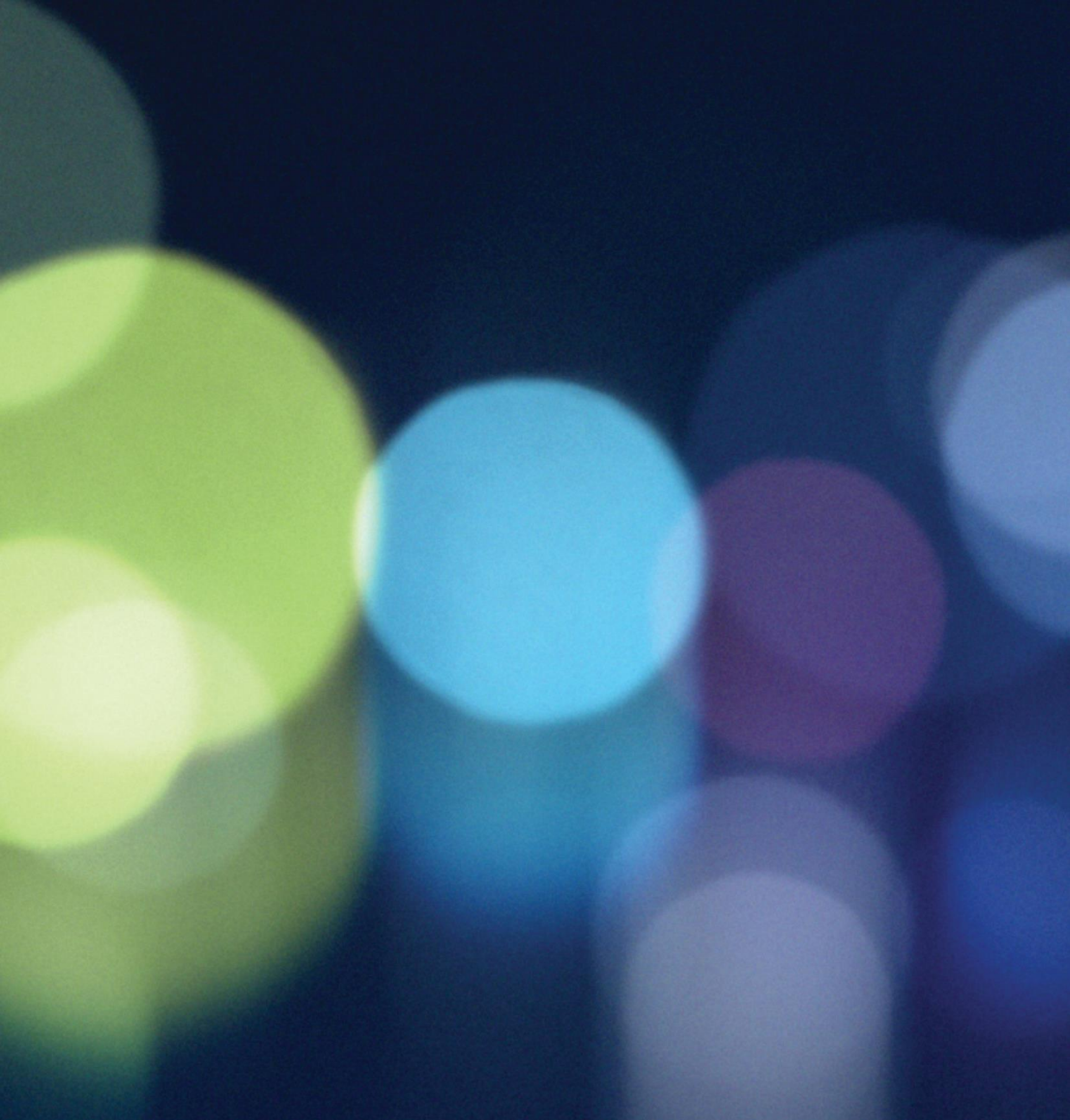
Variable	Commentary	Process
Simultaneous failure constant * PoF	The constant is an empirical value with a significant impact on the value assessment. Test impact of a modest variation of +/- 25%	Re-run FME with varying values of the constant to reflect each scenario. This will produce an Assets file with a different Reliability CoF and Financial CoF for each asset for each scenario. Load revised Assets file into Copperleaf PA and re-run predictive Analytics for each of the three scenarios.
Probability of failure	The PoF vs age function calculated by the CNAIM model has a significant impact on the value assessment. However, its involved method of calculation does not lend itself to a sensitivity adjustment and therefore leave as calculated	Leave the same for each scenario .
Capital cost	Can vary due to varying scope of bund works and cable replacement works required. Test impact of a modest variation of +/-25%	Scale the replacement cost in FME and updated the Assets file.
Value of customer (VCR)	Standard values set by the regulator and applied to each substation based the distribution of connected customers. Impacts the reliability risk but is considered to be a stable variable.	Leave the same for each scenario.
Outage duration due to failure	Can vary widely and has a direct and material impact on the reliability risk value. Test impact of a modest variation of +/- 25%	Scale the Reliability risk CoF in FME and updated the Assets file.

Appendix 3 – Replacement assessment check

The table below summarises the check for alternatives to the direct like for like replacement of the power transformers identified for risk-based replacement in the next RCP. A range of other transformers were also identified for replacement during the period. These include other units at each of the five identified substations and the transformer at the Visy Paper customer substation. The alternate transformers at each of the five substations have been removed from the results following the strategy discussed in 3.2. The transformer at the Visy Paper is reasonably young at 17 years and is in good condition. However, as it is a single transformer substation, there is a very high CoF and hence a tendency to signal the transformer for replacement early. This is typical of single transformer customer substations. However, since the customer is only paying for a supply without redundancy, the model needs to be adjusted to take this into account by reducing the CoF (by reducing the VCR value applied) in future cases for investment.

Test for alternative network options

Proposed replacements	Equipment number	Test for continued need for the transformer and capacity requirements	Replacement Response
Wombarra ZS No. 1	175074	Summer Demand Forecast [3] 50% POE – 5.7MVA Winter demand forecast [4] 50% POE – 6.9MVA Current 2 x 5MVA provides firm capacity - 5MVA Nil scope for permanently reducing demand Check for impedance matching and load sharing	Standardised 33/11kV 15MVA low noise TX. Retains current firm capacity
South Wollongong ZS No. 2	175127	Summer Demand Forecast 50% POE – 11.9MVA Winter demand forecast 50% POE – 12.4MVA Current 2 x 19MVA provides firm capacity - 19MVA Nil scope for permanently reducing demand Check for impedance matching and load sharing	Standardised 33/11kV 25MVA low noise TX. Retains current firm capacity
Unanderra ZS No. 1	175130	Summer Demand Forecast 50% POE – 12.2MVA Winter demand forecast 50% POE – 22.9MVA Current 3 x 12.5MVA provides firm capacity - 25MVA Nil scope for permanently reducing demand Check for impedance matching and load sharing	Standardised 33/11kV 15MVA low noise TX. Retains current firm capacity
Warilla ZS No. 2	902785	Summer Demand Forecast 50% POE – 15.6MVA Winter demand forecast 50% POE – 20.0MVA Current 2 x 10MVA + 1 x 12.5MVA provides firm capacity - 20MVA Nil scope for permanently reducing demand Check for impedance matching and load sharing	Standardised 33/11kV 15MVA low noise TX Retains current firm capacity Long-term strategy = 3 x 15MVA transformers
Port Central ZS No. 1	175123	Summer Demand Forecast 50% POE – 9.0MVA Winter demand forecast 50% POE – 12.2MVA Current 2 x 19MVA provides firm capacity - 19MVA Check for impedance matching and load sharing	Standardised 33/11kV 25MVA low noise TX Retains current firm capacity
Proposed replacements	**Equipment number**	**Test for refurbishment options**	**Program response**
Wombarra ZS No. 1	175074	Age of 61 years is past the economical age for refurbishment	Retain in replacement program
South Wollongong ZS No. 2	175127	Age of 56 year is past the economical age for refurbishment	Retain in replacement program
Unanderra ZS No. 1	175130	Age of 60 years is past the economical age for refurbishment	Retain in replacement program
Warilla ZS No. 2	902785	Age of 61 years is past the economical age for refurbishment	Retain in replacement program
Port Central ZS No. 2	175123	Age of 54 years is past the economical age for refurbishment	Retain in replacement program



Produced by Asset Planning and Performance Branch

W Endeavourenergy.com.au
E news@endeavourenergy.com.au
T 131 081

ABN 11 247 365 823

Endeavour Energy