Sub-transmission circuit breaker failure risk mitigation

Case for investment FY25 - 29
(Pre-optimisation)

July 2022

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1. Executive summary

1.1 Recommendation

This case for investment (CFI) recommends investment in replacement of sub-transmission circuit breakers (CBs) and switchboards across the network during the period of FY25 – FY29 to address the reliability, safety and financial risks associated with this 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 works is estimated to be $32.79 million in real FY25 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 $420,000 is proposed for the replacement of circuit breakers that fail unexpectedly and in a non-repairable manner during the FY25 – FY29 period giving a total proposed investment of $33.21 million.

1.2 Identified need

Endeavour Energy has a fleet of 4,487 individual sub-transmission circuit breakers in service at 132, 66, 33, 22 and 11kV. These circuit breakers are in service in zone and transmission substations and switching stations and customer substations throughout the network and are used to switch electrical circuits for planned works and to clear faults on the network.

The need is that circuit breakers form a critical link in the supply of electricity to customers and any functional failure of a circuit breaker is likely to cause a break in the supply chain and loss of supply to customers, depending on the location of the CB in the network. Circuit breakers switch large amounts of energy and as their contacts and insulation degrades over time there is an increasing risk of a destructive failure. Circuit breakers are tested regularly and ideally all functional failures should be able to be avoided by appropriate intervention as deterioration of condition is observed. However, in practice, functional failures occur, albeit rarely, and have significant consequences, which may include:

- A safety risk to persons present near the circuit breaker at the time of the incident;
- Loss of supply to customers, depending on the function of the breaker and type and topology of the substation where the breaker is located;
- A financial impact of switching around the failed asset, cleaning up damage, investigating the incident and replacing equipment in adjacent bays damaged by the failure; and
- Reactive capital costs – the cost of replacing the failed circuit breaker or switchboard in a reactive manner.

The consequences of failure vary dramatically from circuit breaker to circuit breaker depending on the network topology of their location and hence the reliability impact of the failure. Overall, however, reliability is the principal risk which drives proactive circuit breaker retirement and replacement.

There are also conditional failures which have an economic value and increase the service cost of the asset beyond average values. These are captured under the umbrella of *maintenance* costs and include:

- Additional maintenance to address oil/SF_6 gas leaks and mechanical failures; and
- The environmental impact of leakage of SF_6 gas.

(Note that these impacts are economic only and have not been included in the cost benefit assessment due to the lack of agreement on the value of these emissions within the Australian electricity industry).

1.3 Options Analysis

There are no credible non-network options for replacing the functionality of a sub-transmission circuit breaker given their relatively low replacement cost and the large amount of energy which flows through them on a continual basis.

For free-standing circuit breakers the only option available for addressing the failure risk of individual circuit breakers in a proactive planned manner which is considered to be credible is retirement followed by the replacement of the breaker with a modern equivalent circuit breaker.

For circuit breakers which are part of a switchboard there may be up to three options:

a) Replacement of just the circuit breaker truck with a new truck;
b) Replacement of the entire circuit breaker unit with a new circuit breaker; or
c) Replacement of the entire switchboard or specific sections of the switchboard.

The options which are available for each switchboard depend on the voltage and type of the circuit breaker trucks, the construction and condition of the busbars, the availability of replacement options in the market and the physical size and layout of the building housing the switchboard.

Table 1 below summarises the outcomes of the cost-benefit assessment for the circuit breaker replacement for Endeavour Energy's fleet of 4,487 circuit breakers compared to the counterfactual case, which includes operating the circuit breakers until failure ("run to failure") and then replacing them. The summary shows the impact of investment in the replacement of circuit breakers whose net present value (NPV) of intervention reaches its maximum value in the FY25 - FY29 period.

Table 1 – Option economic evaluation summary

Option	Option type	Volume of inter-ventions	Residual risk ($M)	PV of benefits ($M)	PV of investment ($M)	NPV ($M)	Average BCR	Rank	Comments
Run to failure	Counter-factual	-	1,095.7	-	-	-	-	2	Not preferred as it presents a high level of risk
1. Replacement of CBs and switchboards as appropriate to each location	Network	44	1,022.0	73.67	31.98	41.69	3.66	1	Preferred as it reduces risk and presents a positive NPV. Comprised of a suite of credible replacement solutions specific to each type of circuit breaker/ switchboard

1.4 Recommended option

The recommended option is Option 1, which includes the replacement of 44 circuit breakers/switchboards/ switchboard circuit breaker trucks that are assessed as reaching their maximum NPV in the FY25 – FY29 period.

The NPV of the proposed interventions is unique to each circuit breaker and varies from $82,000 to $2.923 million with an average of $947,000 across the 44 assets proposed for intervention during the period. The total NPV of the proposed program is $41.69 million.

The benefit to cost ratio (BCR) for each circuit breaker varies from 1.1 to 13.0 and averages 3.7 across the 44 interventions.

1.5 Budget

The total cost of the proactive replacement works is estimated to be $32.79 million in real FY25 terms.

The additional funding proposed for circuit breakers that are likely to fail in service is $0.42 million giving a total for the recommended funding of $33.21 million.

2. Purpose

The purpose of this document is to seek endorsement of the case for investment (CFI) for managing the risks posed by aged sub-transmission circuit breakers throughout the network.

This CFI recommends the proactive intervention for the retirement and subsequent replacement of the identified circuit breakers during the FY25 – FY29 period and provision of additional capital for the reactive replacement of circuit breakers 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 has a fleet of 4,487 individual sub-transmission circuit breakers in service at voltages of 132kV, 66kV, 33kV, 22kV and 11kV. These circuit breakers are in service in zone and transmission substations, switching stations and customers substations and are used to switch electrical circuits for planned works and to clear faults on the network.

The circuit breakers use oil, SF_6 gas or vacuum for insulation and/or for quenching the electrical arc that forms during switching.

Many individual circuit breakers are part of indoor switchboards and in some cases in the assessment that follows in this CFI, the switchboard is considered as the asset, rather than the individual circuit breakers.

Table 2 below shows the breakdown of the fleet of individual circuit breakers by voltage and insulation/arc quenching medium.

Table 2 – Circuit breaker fleet summary

Voltage (kV)	Insulating/arc-quenching medium				Totals
	Bulk oil	Small oil	SF_6	Vacuum	
132	-	16	397	-	413
66	-	27	158	1	186
33	208	8	130	626	972
22	-	-	3	55	58
11	500	2	284	2,072	2,858
Total	**708**	**53**	**972**	**2,754**	**4,487**

The current fleet of circuit breakers has been installed progressively as the network has expanded and been renewed over the last 60 or so years. Figure 1 shows the current age profile of the fleet of circuit breakers, in terms of their calendar age and also their age adjusted for condition. Assets with no significant maintenance issues are initially given three years additional life which has resulted in the large number of assets shown in the age profile below with a conditional age of zero years.

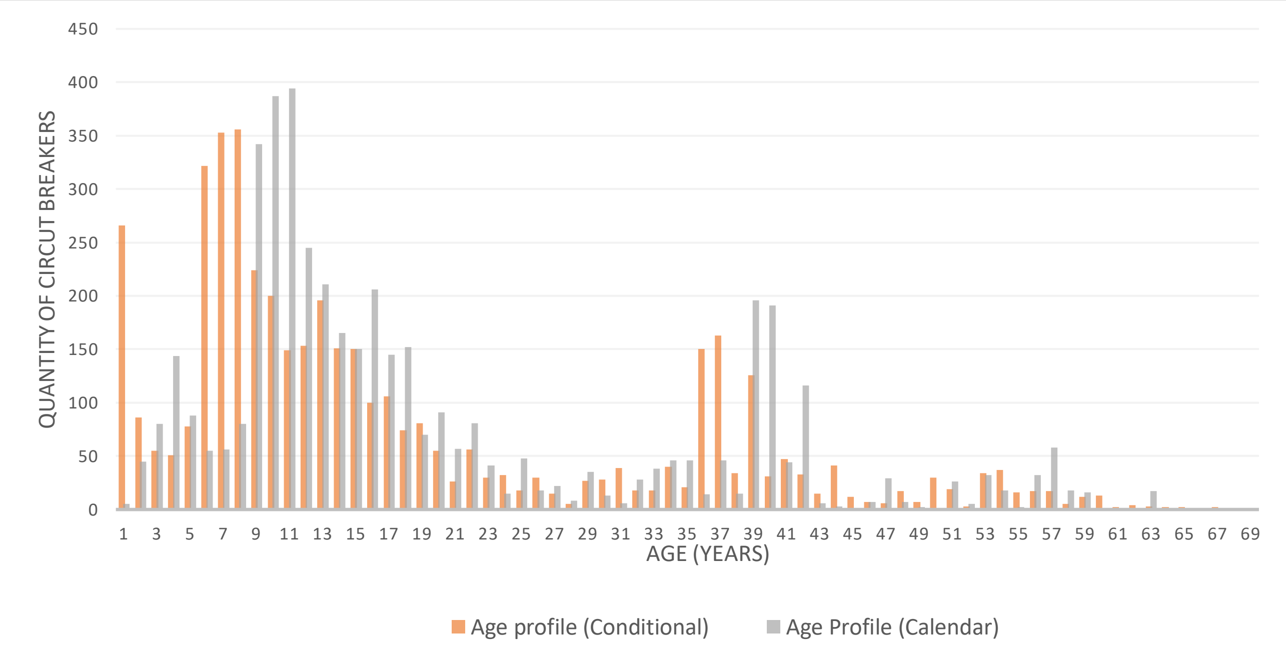
In the recent past, programs have been undertaken to replace circuit breakers of various types as they reach the end of their lives. Currently, the replacement of a range of 132kV and 66kV small-oil circuit breakers, 33kV bulk oil circuit breakers and the 33kV oil switchboard at South Wollongong Zone Substation are approved and their projects are in progress. Furthermore, there is a program in progress to replace a range of bulk-oil 11kV circuit breaker trucks in zone substations with vacuum trucks to extend the life of the 11kV switchboards in those substations.

The sites of new substations and recent retirement/replacements of circuit breakers are summarised in Table 3 below for information.

Table 3 – Recent new and replaced circuit breaker sites summary

Works	Sites
Newly established substations	North Leppington, South Leppington, South Marsden Park and Marayong zone substations
132/66/33kV CB replacements	Blacktown, Fairfax Lane, Hawkesbury, Mount Terry, and Nepean transmission substations and Albion Park, Cabramatta, Kellyville, Minto, Quakers Hill, Riverstone, Rooty Hill and South Bulli zone substations
11kV oil switchboard replacements	Horsley Park, Kellyville, Moss Vale, North Rocks and Port Central zone substations
11kV oil CB truck replacements	Cabramatta, Dundas, Homepride, Luddenham, Riverstone and South Wollongong zone substations

Figure 1 – Individual circuit breaker age profile



3.2 Risks and identified need

Sub-transmission circuit breakers have a range of failure modes. *Conditional* failures include failing to pass tests of:

- Speed of opening and closing;
- Insulation resistance;
- Bushing dielectric loss-angle; and
- Corrosion of casings; and
- Leakage of oil/SF_6 gas.

Conditional failures generally have no immediate consequences but indicate impending *functional* failure.

Functional failures include:

- Failure to operate when required;
- Failure to clear a fault, which may lead to the destructive failure of the circuit breaker;
- Failure of insulation, leading the destructive failure of the circuit breaker.

Functional failures result in consequences which may include:

- Loss of supply to customers, depending on the type and topology of the substation;
- A safety risk to persons present near the circuit breaker at the time of the incident;
- A financial impact of switching around the failed asset, cleaning up damage, investigating the incident and replacing equipment in adjacent bays damaged by the failure; and
- Reactive capital costs – the cost of replacing the failed circuit breaker or switchboard in a reactive manner.

There are also conditional failures which have an economic value and increase the service cost of the asset beyond average values. These are captured under the umbrella of *maintenance* costs and include:

- Additional maintenance to address oil/SF_6 gas leaks and mechanical failures; and
- The environmental impact of leakage of SF_6 gas.

  (Note that these costs are economic only and have not been included in the cost benefit assessment due to the lack of agreement on the value of these emissions within the Australian electricity industry).

The consequences of failure vary significantly from circuit breaker to circuit breaker depending largely upon the network topology of their location and hence the reliability impact of the failure. The sensitivity to network topology is due to the fact that on failure, the failed CB is isolated from the rest of the network by the surrounding circuit breakers opening. Depending on the network topology, the reliability impact of this varies from nil to the loss of supply from an entire zone substation for an extended period whilst the network is reconfigured by manual switching of disconnectors on site and/or transferring customer load to other sources of supply.

Overall, however, reliability is the principal risk which drives proactive circuit breaker retirement and replacement.

The conditional age of each circuit breaker is adjusted based on the level of additional fault-based and condition-based maintenance required of the breaker over the last 10 years and averaged on an annual basis. The economic costs reflecting the environmental impact of SF_6 gas leaks over the last five years is also calculated for inclusion with the additional maintenance costs to reflect the total service cost of each breaker on an annual basis. As noted above however, currently the value of the SF_6 leakage is not included in the final cost benefit assessment.

Switchboards which encompass a number of circuit breakers are assessed as a single asset for the cases where the destructive functional failure of any constituent breaker will result in the need to replace the entire switchboard. This is generally the case where the circuit breakers are insulated with oil and also for the earlier designs of SF_6 and vacuum circuit breaker switchboards without full air-tight compartmentalisation between each circuit breaker and each busbar chamber.

On this basis, for the remainder of this CFI, the term "circuit breaker" may refer to individual circuit breakers as well as some whole or parts of switchboards.

Refer Appendix C for further detail of the assessed failure consequences and the variables used to develop the asset value model which reflects the service costs associated with each asset.

4. Consequence of nil intervention

4.1 Consequences of nil capital intervention

The nil intervention case involves not carrying out any capital works. Therefore, circuit breakers 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 consequences of failure for each CB as noted in 3.2 above as well as the gradual loss of elements such as sub-transmission lines, power transformers and distribution feeders to customers from the network; and
- The flow-on risk costs associated with losing key sub-transmission elements from the network.

The failure of the sub-transmission network would result 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 [1].

On this basis, the reactive replacement of circuit breakers 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 the circuit breakers until they suffer a non-repairable functional failure, or a conditional failure, after which they are replaced with a modern equivalent asset, providing the service provided by the circuit breaker is still required. Nil proactive capital intervention is carried out.

The scope of work under run to failure (RTF) includes:

- Maintenance of the circuit-breakers, which currently includes routine preventative and condition-based maintenance [2] [3] [4] [5]:
  - Routine visual inspection and thermo-vision test;
  - Routine operational checks;
  - Routine timing, insulation resistance, contact resistance and bushing dielectric dissipation factor (DDF) tests;
  - Cleaning of contacts and greasing of mechanisms; and
- Reactive replacement after a non-repairable functional failure.

RTF also includes the replacement of circuit breakers after specific conditional failures are recorded and after an engineering review of the breaker and its condition. The conditional failures which may trigger review for replacement include:

- High contact resistance which cannot be sufficiently improved by dressing the contacts;
- Low insulation resistance which cannot be corrected;
- High bushing DDF which cannot be addressed through replacement of the bushings;
- Repeated failure to operate which cannot be corrected by maintenance; and
- Oil or SF_6 gas leaks which become excessive and cannot be adequately managed through scheduled top-ups.

For the purposes of assessing risk, all CBs which are currently approved for replacement and whose works are in progress, have been removed from the fleet of assets. Therefore, the RTF risk includes only the risk presented by assets not currently approved for replacement.

A summary of the risk presented by the RTF/counterfactual case is shown in Table 4 below. All costs are in real FY25 terms and are present values (PV) over the period of assessment. A discount rate of 3.26% has been used throughout the economic evaluation.

Table 4 – RTF risk cost summary

Risk category	PV of residual risk ($M)	Risk proportion (%)
Reliability	887.9	81.4
Reactive capital replacement costs	174.8	15.6
Financial	22.7	2.1
Safety	10.3	0.9
Bushfire	0.0	0
Environmental	0.0	0
Total	**1,095.7**	**100**

As noted in Table 4 above, the residual risk presented by the RTF case is predominantly due to reliability risk and totals $1,096 million. The residual risk value presented by each circuit breaker ranges from $14,000 to $8.03 million and averages $291,000 across the fleet.

The higher risk values are considered to be excessive and indicate the need for the higher risk circuit breakers to be retired in order to mitigate the risk. On this basis, options for intervention should be considered to provide for the continuation of the service provided by these assets.

5. Options considered

5.1 Risk treatment options

Before assessing the network intervention options, consideration has been given to a range of alternative approaches which could possibly contribute to addressing the risk presented by the circuit breakers. These approaches are summarised in Table 5 below.

Table 5 – Circuit breaker risk treatment options

Option	Assessment of effectiveness	Conclusion
Additional maintenance to extend the life of the existing asset	Maintenance procedures are able to ensure an otherwise sound CB asset reaches its full life potential. Unavailability of replacement parts for aged assets limits the extent to which maintenance can extend the life of a circuit breaker.	No technically feasible solution in isolation
Reduce the load on the asset through network reconfiguration, network automation, demand management or other non-network options	The risk of failure is generally independent of load. A minor reduction in the consequences of failure could be achieved by transferring load from any of the CBs but there is little capacity to do this in the surrounding network at any scale. The circuit breakers are integral to the supply to their substations which are required to carry load for the foreseeable future. Further, there are no practicable non-network solutions for replacing a zone or transmission substation. Disconnecting and bridging out a CB will reduce the discrimination of protection systems and increase the reliability impact on customers of faults that occur in that part of the network.	No technically feasible solution

Option	Assessment of effectiveness	Conclusion
Implementing operational controls such as limiting access, remote switching protocols etc	These controls are in place to limit the safety risks presented by this equipment to workers, but the principal risk that drives the need for intervention is reliability, which cannot be affected by practicable controls.	Controls only the safety risk elements for workers
A combination of options together or staged to maintain option value and reduce the consumer's long-term service cost	CB truck replacement is an option at 11kV and is being pursued as a lower cost and staged approach to whole switchboard replacement across the network. At voltages above 11kV, truck replacement is not an option and compete replacement of circuit breakers and switchboards needs to be considered.	Recommended approach

5.2 Non-network options

The circuit breaker is an integral part of transmission and zone substations and switching stations and generally they carry large loads on a continual basis. As a result, there are no practicable non-network solutions for replacing the service they provide.

Therefore, network options should be considered which include intervention to address the identified need.

5.3 Credible network options

For free-standing circuit breakers the only option available for addressing the failure risk of individual circuit breakers in a planned proactive manner which is considered to be credible is retirement followed by the replacement of the breaker.

For circuit breakers which are part of a switchboard there may be up to three options for replacement –

a) Replacement of just the circuit breaker truck with a new truck;
b) Replacement of the entire circuit breaker unit with a new circuit breaker; or
c) Replacement of the entire switchboard or specific sections of the switchboard.

The options which are available for each switchboard depends on the voltage and type of the circuit breaker trucks, the construction and condition of the busbars, the availability of replacement options in the market and the physical size and layout of the building housing the switchboard. Where multiple options are practicable, they will each be tested for economic value.

In the past, circuit breakers which have been made surplus due to major substation redevelopment works have been re-purposed to other substations to replace similar breakers at the end of their lives. This appeared to provide a lower cost alternative to replacement with a new circuit breaker. However, in practice, the re-purposed breakers appeared not to be reliable from both a mechanical and SF_6 gas leakage perspective and therefore it is not proposed to continue this practice.

5.3.1 Circuit breaker replacement

Under this approach (Option 1), the intervention includes the complete replacement of the circuit breaker in a planned proactive manner to allow for the retirement of the existing breaker.

In the case of individual circuit breakers, located outdoors or in chambers, the replacement breakers are currently dead-tank units insulated with vacuum at 33kV, vacuum or SF_6 gas at 66kV and SF_6 at 132kV.

Further, a number of 33kV oil insulated switchboards and 11kV oil insulated and SF_6 insulated circuit breakers in switchboards are also showing high values of RTF risk. The only replacement strategy available for 33kV CBs in switchboards is the replacement of the entire switchboard. At 11kV the replacement of the circuit breaker trucks with vacuum CB trucks may also be an option alongside the replacement of the entire switchboard. Whole switchboard replacement may appear to be less costly than vacuum truck replacement in some situations but may not be feasible due to the size and shape of the switch room building and the penetrations in the floor for the 11kV cable entry. Supply security issues during the replacement works is also often an impediment to the whole switchboard replacement approach.

The replacement approaches available for each circuit breaker and switchboard type and the estimated costs are shown in Table 6 below. All costs are in real FY25 terms.

Table 6 – Option 1 circuit breaker replacement costs

Circuit breaker type	Proposed replacement type	Estimated replacement cost ($)
132kV and 66kV outdoor CB	SF_6 or vacuum dead-tank CB	219,000
33kV bulk-oil dead-tank outdoor CB	Vacuum dead-tank CB	221,000
33kV bulk-oil dead-tank indoor chamber CB	Vacuum dead-tank CB	374,000
33kV SF_6 live-tank outdoor CB	Vacuum dead-tank CB	221,000
33kV small-oil live-tank outdoor CB	Vacuum dead-tank CB	221,000
11kV SF_6 indoor switchboard CB	Vacuum trucks[1]	80,000 (per truck replacement)
	Switchboard replacement	2,585,000
11kV bulk oil indoor switchboard CB	Vacuum trucks[2]	46,000 – 80,000 (per truck replacement)
	Switchboard replacement	344,000 – 3,877,000

5.4 Economic evaluation

The proposed program under Option 1, identifies 44 circuit breakers/switchboards whose NPV of replacement is positive and reaches a maximum value during the FY25 – FY29 period. This option presents a residual risk of $1,022 million and provides a benefit of $73.67 million compared to the counterfactual RTF case. The PV of the cost of Option 1 is $31.98 million and the NPV overall is $41.69 million. The NPV of the individual asset replacements ranges from $82,000 to $2.92 million with an average value of $948,000. The cost of the option in real FY25 terms is $32.79 million.

Table 7 below provides a summary of the residual risk presented by Option 1. Refer Appendix A for details of the circuit breakers identified for intervention during the FY25 – FY29 period under this option.

Table 7 – Option 1 residual risk summary

Risk category	PV of residual risk ($M)	Risk proportion (%)
Reliability	828.2	81.4
Reactive capital replacement costs	163.0	15.6
Financial	21.2	2.1
Safety	9.6	0.9
Bushfire	0.0	0
Environmental	0.0	0
Total	**1,022.0**	**100**

[1] Replacement of all SF_6 trucks in the switchboard with vacuum trucks is considered to be a more practicable solution than replacing just the worst performing SF_6 trucks and being left with a patchwork of different circuit breakers in the switchboard. The trucks are custom made with economies of scale where the larger volumes required for whole switchboard replacements make production feasible.

[2] As above

5.5 Evaluation summary

Table 8 below summarises the outcomes of the cost-benefit assessment for the circuit breaker replacement for Endeavour Energy's fleet of 4,487 circuit breakers compared to the RTF case. The summary shows only the impact of investment in the circuit breakers whose NPV of intervention reaches its maximum value in the FY25 - FY29 period.

Table 8 – Option economic evaluation summary

Option	Option type	Volume of inter-ventions	Residual risk ($M)	PV of benefits ($M)	PV of investment ($M)	NPV ($M)	Average BCR	Rank	Comments
RTF	Counter-factual	-	1,095.7	-	-	-	-	2	Not preferred as shows excess levels of risk
1. Replacement of CBs and switchboards as appropriate	Network	44	1,022.0	73.67	31.98	41.69	3.66	1	Preferred as it reduces risk and provides a positive NPV. Comprised of a suite of credible CB replacement solutions

Due to the constraints associated with each site and the types of switchboards, there is generally only a single practicable solution for each switchboard assessed in this CFI with replacement of circuit breaker trucks and whole switchboard replacements modelled as appropriate for each location.

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 RTF and to other timings for the interventions.

5.6 Economic evaluation assumptions

There are a wide range of assumptions of risk, their likelihoods and consequences which support the cost benefit assessment associated with this project. Refer Appendix C for details of these assumptions.

5.7 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 9 below.

Table 9 – Summary of scenarios investigated

Variable	Scenario 1 – low benefits, high capital costs	Scenario 2 – central values	Scenario 3 – high benefits, low capital costs
Capital cost	5% increase in the estimated network capital costs	Estimated network capital costs	5% decrease in the estimated network capital costs
Value of risk (combination of consequence of the failure risk and the likelihood of the consequence eventuating)	10% decrease in the estimated risk and benefit values	Estimated risk values	10% increase in the estimated risk and benefit values
Weibull distribution end-of-life failure characteristic	5% increase in the Weibull β parameter (increases the mean time to failure for the asset)	Estimated Weibull parameters based on available failure data and calibrated to observed failure rates	5% decrease in the Weibull β parameter (decreases the mean time to failure for the asset)

The impact on the preferred option NPV is shown in Table 10 below and the resultant spread of replacement years to give the maximum NPV for each of the 44 circuit breakers identified for replacement under the preferred option is shown in Figure 2.

Table 10 – NPV of scenario analysis for the preferred option (Option 1)

Scenario	NPV of preferred option ($M)
Scenario 1 – Low benefits, high costs	16.11
Scenario 2 – Central risks and costs	41.69
Scenario 3 – High benefits, low costs	67.15

Figure 2 – Maximum NPV replacement years for the range of boundary scenarios

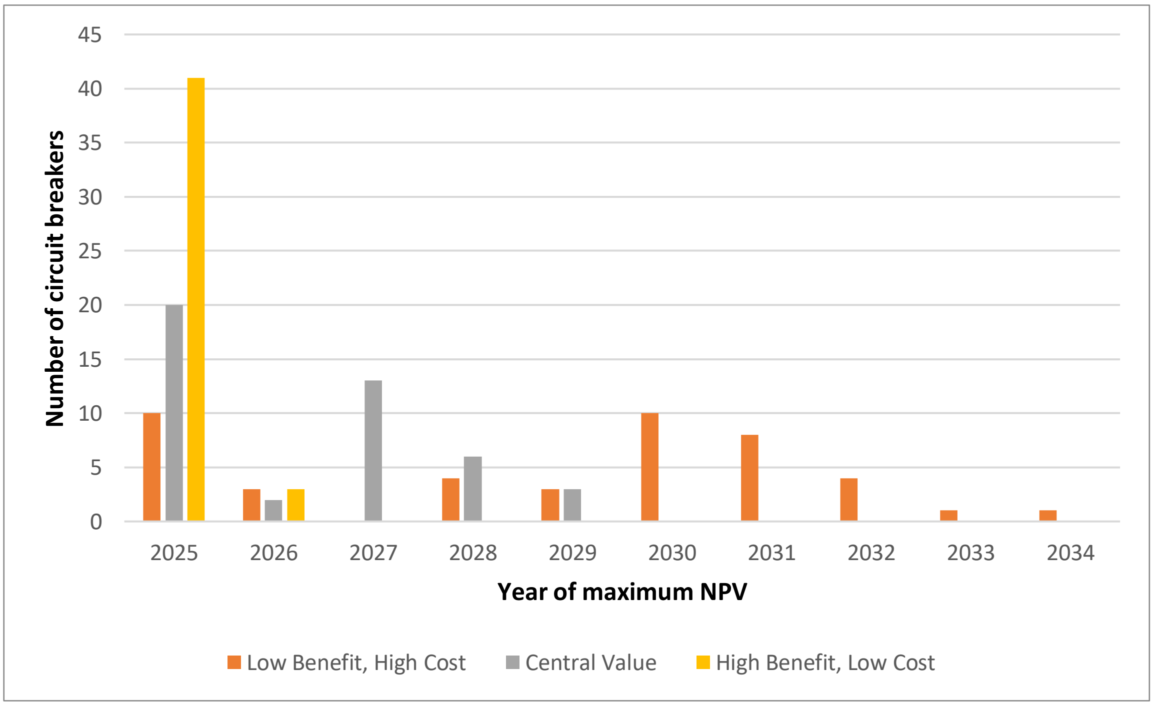


Figure 2 shows that the recommended replacement interventions are centred around FY27. All high-benefit, low-cost cases fall in the FY25 – FY26 period, while the low-benefit, high-cost cases are centred around 2030 and spread out to FY34. The scenario assessment further indicates that the variations in the value of risk and the capital costs had only minor impacts on the year of maximum NPV but that the assessment was particularly sensitive to the Weibull β (scale) parameter.

This assessment shows that there is a reasonable spread of optimum replacement years across the range of boundary scenarios but that the range is skewed towards the start of the period. On this basis it is concluded that the preferred solution (Option 1) is appropriate under different scenarios and represents an appropriate level of investment.

6. Preferred option details

6.1 FY25 – FY29 scope and timing

The preferred program includes the replacement of 44 circuit breakers/switchboards during FY25 – FY29.

The overall cost of the proposed program is estimated to be $32.79 million. A contingency is not proposed to be applied as there are multiple sites in the program and the estimated costs are based on mean values with individual site costs likely to even out to the mean across the program.

6.2 Additional scope and timing

Replacement intervention on a further 28 circuit breakers/switchboards is NPV positive and reaches its maximum NPV within the forecast period from FY30 - FY34. These 28 investments total a further $13.45 million (in real FY25 terms) and have been identified as additional scope for inclusion in the investment portfolio optimisation process.

6.3 Investment summary

6.3.1 Planned proactive works

A summary of the investment proposed to be submitted for portfolio optimisation is shown in Table 11 below. Refer to Appendix A for the details of the complete list of circuit breakers.

All costs are in real FY25 terms.

6.3.2 Reactive investment

Whilst non-repairable failures of circuit breakers are rare, the modelling shows there is a modestly increasing likelihood of unexpected circuit breaker failures over the period of interest, notwithstanding the recommended program of replacement. Figure 3 below shows the forecast trend of investment likely to be required for the replacement of circuit breakers that reach a state of conditional failure (found to be in a poor condition indicative of imminent failure) and/or fail functionally in a non-repairable manner in the period of FY25 – FY29.

This assessment assumes that the proactive replacement of circuit breakers as recommended by this CFI is carried out and considers only the probability of failure of other circuit breakers, not scheduled for replacement. A reactive replacement cost has been averaged across the fleet of circuit breakers under consideration to give an annual forecast of reactive funding requirements. Table 12 below, summarises the proposed reactive funding forecast.

Table 11 – Summary of investment with maximum NPV in the period FY25 – FY34

NPV criteria	Intervention type	Unit rate ($M)	Quantity of interventions	Total costs ($M)
NPV reaches maximum during FY25 – FY29	Replacement of outdoor 33kV CBs	0.221	23	5.083
	Replacement of 33kV CBs in door chambers	0.374	6	2.244
	Replacement of 33kV switchboards at Bossley Park, Carramar, Emu Plains and Lennox ZSs	2.585	3	7.754
	Replacement of 33kV SF_6 switchboard at Bossley Park	1.077	1	1.077
	Replacement of 11kV bulk oil switchboards at Kentlyn and Macquarie Fields ZSs	3.877	2	7.754
	Replacement of CB trucks in 11kV bulk oil switchboards at Ambarvale, Bossley Park, Glossodia and Woodpark ZSs	Varies	4	2.854
	Replacement of CB trucks in 11kV SF_6 switchboards	Varies	5	6.030
Subtotals FY25 - FY29			**44**	**32.797**
NPV reaches maximum during FY30 – FY34	Replacement of outdoor 132/66kV CBs	0.219	3	0.657
	Replacement of outdoor 33kV CBs	0.220	15	3.315
	Replacement of 33kV CBs in door chambers	0.374	2	0.748
	Replacement of 33kV switchboard CBs	0.254	2	0.508
	Replacement of 33kV oil switchboards at Cranebrook and North Wollongong ZSs	2.585	2	5.170
	Replacement of 11kV oil switchboard at North Wollongong ZS	2.585	1	2.585
	Replacement of 11kV outdoor CB	0.197	1	0.197
	Replacement of 11kV CB trucks	Varies	2	0.274
Subtotals FY30 – FY34			**28**	**13.454**
Totals FY25 - FY34			**71**	**46.251**

Figure 3 – Reactive replacement costs

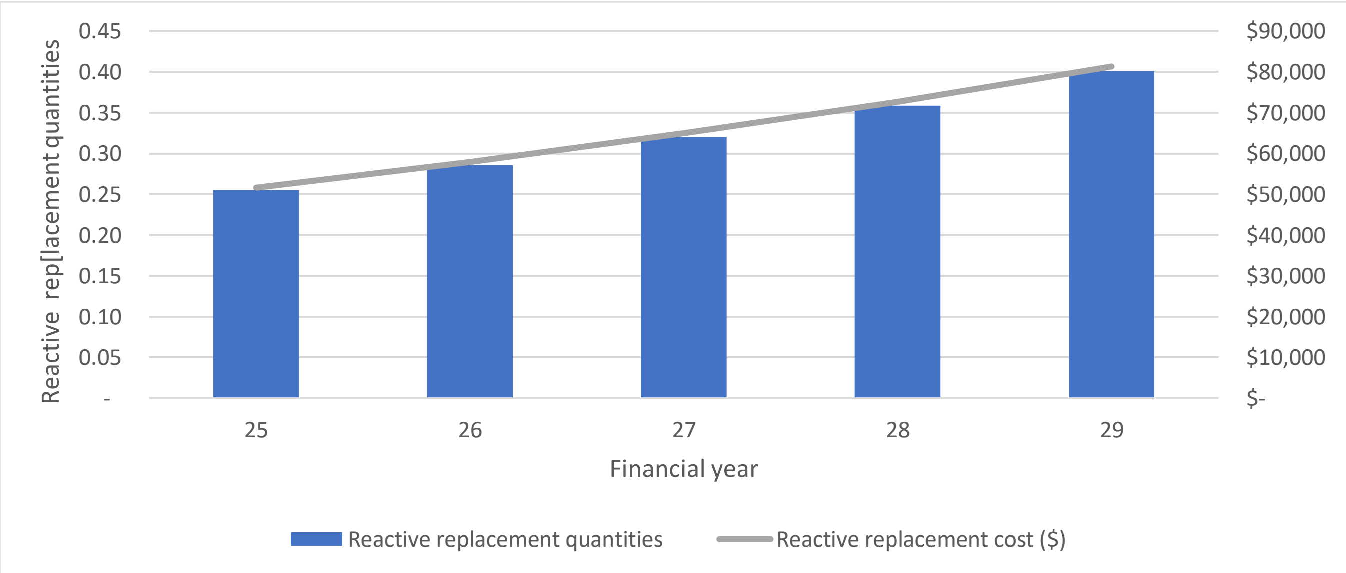


Table 12 – Reactive circuit breaker replacement forecast

Regulatory control period	Forecast quantity of failures	Forecast reactive investment ($M)
FY25 - FY29	2.1	0.42

6.4 Project scope of works

6.4.1 Circuit breaker replacements

The proposed scope for each circuit breaker replacement is generally as outlined below:

- Order and purchase replacement dead-tank circuit breakers as per the existing supply contracts;
- Decommission and remove existing circuit breakers. Where applicable, the post or bar type current transformers associated with live tank circuit breakers shall also be removed;
- Install, testing and commission replacement circuit breakers;
- Update asset information in SAP;
- Dispose of removed equipment. Retain circuit breakers and/or parts for spares as specified by the Region;

6.4.2 Circuit breaker truck replacement

The proposed scope for each circuit breaker truck replacement is generally as outlined below:

- The replacement refers only to the specific type of CBs noted. Refer Appendix B for details of the CB trucks to be replaced in each switchboard. Other sections of the switchboard are to be left in service;
- Test the busbars for partial discharge and the busbar bushings for DDF;
- Provide test results to Asset Planning and Performance for a final decision regarding proceeding with the works;
- On approval by Asset Planning and Performance, order and purchase replacement vacuum circuit breaker trucks for all CBs of that specific type within the switchboard;
- Other sections of the switchboard with different CB types are to be left as they are;
- Decommission and remove existing circuit breaker trucks and any oil insulated bus VTs;
- Install, test and commission replacement circuit breaker truck and replacement bus VTs;
- Update asset information in SAP;
- Dispose of removed equipment. Retain circuit breaker trucks and/or parts for spares as specified by the Region;

6.4.3 Switchboard replacement

The proposed scope for switchboard replacement is generally as outlined below:

- The replacement is for the oil sections of switchboard only. Existing SF_6 or vacuum sections of switchboard are to be left in service (except Bossley Park ZS where the 33kV SF_6 switchboard is to be replaced). Refer Appendix B for details of the sections of switchboard to be replaced;
- Design the switchboard replacement and confirm cabling works required, costs, constraints and arrangements for achieving supply security during the works;
- Order and purchase replacement switchboard;
- Installation, test and commission the new switchboard in a staged manner;
- Decommission and remove existing switchboard;

- Update asset information in SAP; and
- Disposal of removed equipment (switchboard parts may be retained for spares as required by the region).

7. Regulatory investment test

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.

8. Recommendation

It is recommended that the proactive replacement of circuit breakers where the intervention provides a maximum NPV in the period of FY25 – FY34, as outlined as Option 1 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 $0.42 million be made within the FY25 - FY29 period for the reactive replacement of circuit breakers that fail unexpectedly.

9. Attachments

Appendix A – Details of recommended scope for optimisation

Appendix B – Details of the switchboard assets to be replaced

Appendix C – Summary of key risk assessment variables and assumptions

10. References

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

[2] Endeavour Energy, “Substation Maintenance Instruction SMI 100 - Minimum requirements for maintenance of transmission and zone substation equipment,” Endeavour Energy - Asset Standards and Design, 2016.

[3] Endeavour Energy, “Substation Maintenance Instruction SMI 140 - Thermovision of zone and transmission substations,” Endeavour Energy - Primary Systems, 2014.

[4] Endeavour Energy, “Substation Maintenance Instruction SMI 200 - HV Circuit Breakers,” Endeavour Energy, 2019.

[5] Endeavour Energy, “Substation Maintenance Instruction SMI 210 - 132kV indoor air and gas insulated switchgear,” Endeavour Energy - Primary Systems, 2015.

[6] S. LIttle, “AER Repex Model - Endeavour Energy - 18 May 2018 (Benchmarked Lifes) mar1.0,” 2018.

Appendix A – Details of recommended scope for optimisation

Scope with maximum NPV in FY25 – FY29

Voltage (kV)	Site/circuit breaker	Equipment Number	Part number	Intervention type	Budget cost ($)	Year of maximum NPV	NPV at maximum ($)	BCR at maximum
33	KINGSWOOD ZS, 33kV, 457 Penrith	184271	36GI-E25	Dead tank CB	$ 221,000	2025	$ 1,050,000	5.7
	SMITHFIELD ZS, 33kV, 678	185084	345GCN	Dead tank CB	$ 221,000	2027	$ 610,000	3.9
	SEVEN HILLS ZS, 33kV, 475	186198	345GCN	Dead tank CB	$ 221,000	2027	$ 590,000	3.8
	CABRAMATTA ZS, 33kV, 687	183980	345GCN	Dead tank CB	$ 221,000	2028	$ 370,000	2.9
	JASPER ROAD ZS, 33kV, 469	184798	345GCN	Dead tank CB	$ 221,000	2027	$ 550,000	3.6
	YENNORA ZS, 33kV, FDR 685	185725	345GC	Dead tank CB	$ 221,000	2026	$ 450,000	3.1
	GREYSTANES ZS, 33kV, 430	187436	345GCN	Dead tank CB	$ 221,000	2025	$ 540,000	3.4
	SMITHFIELD ZS, 33kV, 745/1	185102	345GCN	Dead tank CB	$ 221,000	2027	$ 610,000	3.9
	SMITHFIELD ZS, 33kV, 676/2	185122	345GCN	Dead tank CB	$ 221,000	2027	$ 610,000	3.9
	JASPER ROAD ZS, 33kV, No 1 Transformer	184835	345GCN	Dead tank CB	$ 221,000	2027	$ 550,000	3.6
	WEST WOLLONGONG ZS, 33kV, No 2	178303	345GC	Dead tank CB	$ 221,000	2027	$ 230,000	2.1
	HORSLEY PARK ZS, 33kV, No 2 Transformer	184343	LGIC/44	Dead tank CB	$ 221,000	2028	$ 270,000	2.3
	GREYSTANES ZS, 33kV, No 1 Transformer	187428	345GCN	Dead tank CB	$ 221,000	2025	$ 540,000	3.4
	HORSLEY PARK ZS, 33kV, No 1 Transformer	184373	LGIC/44	Dead tank CB	$ 221,000	2025	$ 310,000	2.4
	SEVEN HILLS ZS, 33kV, No 2 Transformer	186160	345GCN	Dead tank CB	$ 221,000	2027	$ 590,000	3.8
	YENNORA ZS, 33kV, No 1 Transformer	185715	345GC	Dead tank CB	$ 221,000	2025	$ 470,000	3.1
	JASPER ROAD ZS, 33kV, No 2 Transformer	184808	345GCN	Dead tank CB	$ 221,000	2027	$ 550,000	3.6
	SEVEN HILLS ZS, 33kV, No 3 Transformer	186141	345GCN	Dead tank CB	$ 221,000	2025	$ 630,000	3.8
	CABRAMATTA ZS, 33kV, No 2 Transformer	183940	345GCN	Dead tank CB	$ 221,000	2026	$ 410,000	2.9
	BLACKTOWN TS, 33kV, No 3/4 Section	186618	345GCN	Dead tank CB	$ 374,000	2029	$ 1,560,000	5.8
	WEST LIVERPOOL TS, 33kV, Bus Section 1-4	184870	345GCN	Dead tank CB	$ 374,000	2027	$ 1,120,000	4.2
	WEST LIVERPOOL TS, 33kV, Bus Section 2-3	184875	345GCN	Dead tank CB	$ 374,000	2027	$ 1,120,000	4.2
	WEST LIVERPOOL TS, 33kV, Bus Section 3-4	184863	345GCN	Dead tank CB	$ 374,000	2027	$ 1,120,000	4.2
	MT DRUITT TS, 33kV, No 4 Section	502429	345GCN	Dead tank CB	$ 374,000	2028	$ 770,000	3.3
	OUTER HARBOUR TS, 33kV, No 1/2 Section	177656	345GCN	Dead tank CB	$ 374,000	2029	$ 1,010,000	4.1
	FAIRFAX LANE TS, 33kV	178121	38MGE1500	Dead tank CB	$ 221,000	2025	$ 2,020,000	10.1
	MOUNT TERRY TS, 33kV, No 2/3 Section	177819	345GC	Dead tank CB	$ 221,000	2028	$ 1,420,000	8.1
	MOUNT TERRY TS, 33kV, No 1/2 Section	177818	345GC	Dead tank CB	$ 221,000	2028	$ 1,420,000	8.1
	SHOALHAVEN TS, 33kV, No 1/2 Section	175608	345GCN	Dead tank CB	$ 221,000	2028	$ 2,410,000	13.0
	33kV CB subtotal				**$ 7,327,000**			
	Emu Plains_33kVBULKOIL_IS_2	9565_33kVBULKOIL_IS_2	33L800TX4MO	Replace switchboard	$ 2,585,000	2025	$ 1,940,000	1.8
	Lennox_33kVBULKOIL_IS_2	9562_33kVBULKOIL_IS_2	33L800TX4MO	Replace switchboard	$ 2,585,000	2029	$ 600,000	1.3
	Carramar_33kVSMALLOIL_IS_2	9592_33kVSMALLOIL_IS_2	38MG1500	Replace switchboard	$ 2,585,000	2025	$ 850,000	1.3
	Bossley Park_33kVSF6_IS_2	9597_33kVSF6_IS_2	36GB25	Replace switchboard	$ 1,077,000	2027	$ 80,000	1.1
	33kV switchboard subtotal				**$ 7,755,000**			
11	Kentlyn_11-22kVBULKOIL_IS_3	9584_11-22kVBULKOIL_IS_3	OLX3	Replace switchboard	$ 3,877,000	2025	$ 2,160,000	1.6
	Macquarie Fields_11-22kVBULKOIL_IS_3	9583_11-22kVBULKOIL_IS_3	OLX3	Replace switchboard	$ 3,877,000	2025	$ 2,920,000	1.8
	11kV switchboard subtotal				**$ 7,754,000**			
	Kenny Street_11-22kVSF6_IS_2	9663_11-22kVSF6_IS_2	YSF6	Vacuum trucks	$ 1,034,000	2025	$ 350,000	1.3
	Lithgow_11-22kVSF6_IS_2	9586_11-22kVSF6_IS_2	HB 12.06.25C	Vacuum trucks	$ 1,292,000	2025	$ 230,000	1.2
	Bow Bowing_11-22kVSF6_IS_2	9608_11-22kVSF6_IS_2	YSF6	Vacuum trucks	$ 1,292,000	2025	$ 1,260,000	2.0
	West Pennant Hills_11-22kVSF6_IS_2	9615_11-22kVSF6_IS_2	GK1M1206-25	Vacuum trucks	$ 1,292,000	2025	$ 250,000	1.2
	Newton_11-22kVSF6_IS_2	9598_11-22kVSF6_IS_2	HB 12.06.25C	Vacuum trucks	$ 1,120,000	2025	$ 580,000	1.5
	Bossley Park_11-22kVBULKOIL_IS_2	9597_11-22kVBULKOIL_IS_2	LMT2/X31/MO	Vacuum trucks	$ 644,000	2025	$ 2,100,000	4.3
	Ambarvale_11-22kVBULKOIL_IS_2	9604_11-22kVBULKOIL_IS_2	R4/1 MK8	Vacuum trucks	$ 1,120,000	2025	$ 1,060,000	1.9
	Glossodia_11-22kVBULKOIL_IS_2	9595_11-22kVBULKOIL_IS_2	LMT/X5/MO	Vacuum trucks	$ 446,000	2025	$ 1,360,000	4.0
	Woodpark_11-22kVBULKOIL_IS_2	9594_11-22kVBULKOIL_IS_2	LMT2/X31/MO	Vacuum trucks	$ 644,000	2025	$ 2,090,000	4.2
	11kV truck replacement subtotal				**$ 8,884,000**			
	Total program (rounded)				**$ 32,797,000**			

Scope with maximum NPV in FY30 - FY34

Voltage (kV)	Site/circuit breaker	Equipment Number	Part number	Intervention type	Budget cost ($)	Year of maximum NPV	NPV at maximum ($)	BCR at maximum
132 - 66	BAULKHAM HILLS TS,132kV, No 2-3 Sec	185769	HGF 112/1C	Dead tank CB	$ 219,000	2034	$ 2,160,000	14.2
	KENTLYN ZS, 66kV, No 1 Transformer	182595	HPF409H	Dead tank CB	$ 219,000	2031	$ 450,000	3.5
	KENTLYN ZS, 66kV, No 2 Transformer	182562	HPF409H	Dead tank CB	$ 219,000	2031	$ 450,000	3.5
	132kV CB subtotal				**$ 657,000**			
33	PORT CENTRAL ZS, 33kV, 7036	175606	345GCN	Dead tank CB	$ 221,000	2031	$ 260,000	2.4
	WEST WOLLONGONG ZS, 33kV, 7015	178300	345GC	Dead tank CB	$ 221,000	2033	$ 180,000	2.0
	PORT CENTRAL ZS, 33kV, 7321	175609	345GCN	Dead tank CB	$ 221,000	2031	$ 260,000	2.4
	SEVEN HILLS ZS, 33kV, 479	186168	345GCN	Dead tank CB	$ 221,000	2032	$ 490,000	3.8
	PORT CENTRAL ZS, 33kV, 7032	175607	345GCN	Dead tank CB	$ 221,000	2031	$ 260,000	2.4
	WEST WOLLONGONG ZS, 33kV, 7142	178301	345GC	Dead tank CB	$ 221,000	2034	$ 170,000	2.0
	PORT CENTRAL ZS, 33kV, 7381	175605	345GCN	Dead tank CB	$ 221,000	2031	$ 260,000	2.4
	PORT CENTRAL ZS, 33kV, No 2 Transformer	175604	345GCN	Dead tank CB	$ 221,000	2031	$ 260,000	2.4
	WEST WOLLONGONG ZS, 33kV, No 3	178304	345GC	Dead tank CB	$ 221,000	2030	$ 200,000	2.1
	MOOREBANK ZS, 33kV, No 3 Transformer	185200	345GCN	Dead tank CB	$ 221,000	2033	$ 510,000	4.0
	PORT CENTRAL ZS, 33kV, No 1 Transformer	175603	345GCN	Dead tank CB	$ 221,000	2031	$ 260,000	2.4
	WEST WOLLONGONG ZS, 33kV, No 1	178302	345GC	Dead tank CB	$ 221,000	2030	$ 200,000	2.1
	WOODPARK ZS, 33kV, No 2 Transformer	188718	345GCN	Dead tank CB	$ 221,000	2031	$ 500,000	3.7
	MT DRUITT TS, 33kV, No 3 Section	502464	345GCN	Dead tank CB	$ 374,000	2031	$ 680,000	3.2
	HAWKESBURY TS, 33kV, No 1/2 Section	184044	345GCN	Dead tank CB	$ 221,000	2030	$ 2,150,000	12.4
	WEST LIVERPOOL TS, 33kV, No 2	184969	345GCN	Dead tank CB	$ 374,000	2032	$ 70,000	1.2
	ULLADULLA ZS, 33kV, Feeder 7534	177014	GK1M1213	Dead tank CB	$ 221,000	2031	$ 140,000	1.8
	33kV CB subtotal				**$ 4,063,000**			
	EAST PROSPECT ZS, 33kV, No 1 Section	502266	FG4	CB replacement?	$ 254,000	2033	$ 390,000	3.0
	NEWTON ZS, 33kV, No A/B Section	188881	36GB25	CB replacement?	$ 254,000	2030	$ 440,000	3.0
	33kV switchboard CB subtotal				**$ 508,000**			
	North Wollongong_33kVBULKOIL_IS_2	9668_33kVBULKOIL_IS_2	33L800TX4MO	Replace switchboard	$ 2,585,000	2031	$ 420,000	1.2
	Cranebrook_33kVBULKOIL_IS_2	9564_33kVBULKOIL_IS_2	33L800TX4MO	Replace switchboard	$ 2,585,000	2030	$ 840,000	1.4
	33kV switchboard replacement subtotal				**$ 5,170,000**			
11	North Wollongong_11-22kVBULKOIL_IS_2	9668_11-22kVBULKOIL_IS_2	OLX3	Replace switchboard	$ 2,585,000	2034	$ 400,000	1.2
	11kV switchboard replacement subtotal				**$ 2,585,000**			
	HUSKISSON ZS, 11kV, No 1 Transformer	177169	38MGE1000	Dead tank CB	$ 197,000	2034	$ 240,000	2.7
	11kV CB replacement subtotal				**$ 197,000**			
	INNER HARBOUR ZS, 11kV, No 2/3 Section	177362	3AF1722	Vacuum trucks	$ 137,000	2034	$ 110,000	2.1
	INNER HARBOUR ZS, 11kV, No 1/2 Section	177361	3AF1722	Vacuum trucks	$ 137,000	2034	$ 110,000	2.1
	11kV CB truck replacement subtotal				**$ 274,000**			
	Total program (rounded)				**$ 13,454,000**			

Appendix B – Details of switchboard assets to be replaced

Vacuum trucks are likely to be available for the 11kV ABB HB 12, ABB GK1M and Yorkshire YSF6 SF_6 CBs in service at the substations noted in the table below.

Vacuum trucks are not likely to be available for the 11kV GEC OLX bulk-oil CBs in service at Kentlyn, Macquarie Fields and North Wollongong zone substations and therefore full switchboard replacement has been modelled for these substations.

Full switchboard replacement (of the sections of switchboard with oil CBs) have been modelled for the 33kV indoor switchboards at Carramar, Cranebrook, Emu Plains, Lennox and North Wollongong zone substations. Full switchboard replacement has also been modelled for the Magrini 36GB25 SF_6 switchboard at Bossley Park Zone Substation.

The bus section CBs in the Merlin Gerin FG4 33kV switchboard at East Prospect ZS and the Magrini 36GB25 switchboard at Newton zone substations have also been identified for replacement. However, it is unlikely that individual CB replacements will be practicable at these sites and therefore complete switchboard replacement may be the only credible solution. This will be explored further closer to the proposed intervention date taking into account the experience gained during the replacement of the 33kV switchboards at Emu Plains, Lennox, Carramar and Bossley Park zone substations.

Name	Asset No.	Asset type	Part No.	In-service date	Intervention type	Constituent CBs to replace
FY25 - 29						
Emu Plains_33kVBULKOIL_IS_2	9565_33kVBULKOIL_IS_2	33kVBULKOIL_IS_2	33L800TX4MO	1978	Replace switchboard	Reyrolle 33L800 sections of switchboard
Lennox_33kVBULKOIL_IS_2	9562_33kVBULKOIL_IS_2	33kVBULKOIL_IS_2	33L800TX4MO	1976	Replace switchboard	Reyrolle 33L800 sections of switchboard
Carramar_33kVSMALLOIL_IS_2	9592_33kVSMALLOIL_IS_2	33kVSMALLOIL_IS_2	38MG1500	1981	Replace switchboard	Entire switchboard
Bossley Park_33kVSF6_IS_2	9597_33kVSF6_IS_2	33kVSF6_IS_2	36GB25	1984	Replace switchboard	Entire switchboard
Kentlyn_11-22kVBULKOIL_IS_3	9584_11-22kVBULKOIL_IS_3	11-22kVBULKOIL_IS_3	OLX3	1976	Replace switchboard	Entire 11kV GEC OLX switchboard
Macquarie Fields_11-22kVBULKOIL_IS_3	9583_11-22kVBULKOIL_IS_3	11-22kVBULKOIL_IS_3	OLX3	1971	Replace switchboard	Entire 11kV GEC OLX switchboard
Kenny Street_11-22kVSF6_IS_2	9663_11-22kVSF6_IS_2	11-22kVSF6_IS_2	YSF6	1988	Vacuum trucks	Trucks for all 12 Yorkshire YSF6 CBs
Lithgow_11-22kVSF6_IS_2	9586_11-22kVSF6_IS_2	11-22kVSF6_IS_2	HB 12.06.25C	1984	Vacuum trucks	Trucks for all 14 ABB HB 12 CBs
Bow Bowing_11-22kVSF6_IS_2	9608_11-22kVSF6_IS_2	11-22kVSF6_IS_2	YSF6	1986	Vacuum trucks	Trucks for all 15 Yorkshire YSF6 CBs
West Pennant Hills_11-22kVSF6_IS_2	9615_11-22kVSF6_IS_2	11-22kVSF6_IS_2	GK1M1206-25	1987	Vacuum trucks	Trucks for all 15 ABB GK1M CBs
Newton_11-22kVSF6_IS_2	9598_11-22kVSF6_IS_2	11-22kVSF6_IS_2	HB 12.06.25C	1984	Vacuum trucks	Trucks for all 12 ABB H12 CBs
Bossley Park_11-22kVBULKOIL_IS_2	9597_11-22kVBULKOIL_IS_2	11-22kVBULKOIL_IS_2	LMT2/X31/MO	1984	Vacuum trucks	Trucks for all 22 Reyrolle LMT CBs
Ambarvale_11-22kVBULKOIL_IS_2	9604_11-22kVBULKOIL_IS_2	11-22kVBULKOIL_IS_2	R4/1 MK8	1979	Vacuum trucks	Trucks for all 13 HSB Q20 and R4 CBs
Glossodia_11-22kVBULKOIL_IS_2	9595_11-22kVBULKOIL_IS_2	11-22kVBULKOIL_IS_2	LMT/X5/MO	1983	Vacuum trucks	Trucks for all 9 Reyrolle LMT CBs
Woodpark_11-22kVBULKOIL_IS_2	9594_11-22kVBULKOIL_IS_2	11-22kVBULKOIL_IS_2	LMT2/X31/MO	1984	Vacuum trucks	Trucks for all 13 Reyrolle LMT CBs
FY30 - 34						
EAST PROSPECT ZS, 33kV, No 1 Section	502266	33kVSF6_IS	FG4	1994	Replace CB/replace switchboard?	Likely to need complete switchboard replacement with additional funding requirement
NEWTON ZS, 33kV, No A/B Section	188881	33kVSF6_IS	36GB25	1984	Replace CB/replace switchboard?	As above
North Wollongong_33kVBULKOIL_IS_2	9668_33kVBULKOIL_IS_2	33kVBULKOIL_IS_2	33L800TX4MO	1978	Replace switchboard	Entire 33kV switchboard
Cranebrook_33kVBULKOIL_IS_2	9564_33kVBULKOIL_IS_2	33kVBULKOIL_IS_2	33L800TX4MO	1978	Replace switchboard	Reyrolle 33L800 sections of switchboard
North Wollongong_11-22kVBULKOIL_IS_2	9668_11-22kVBULKOIL_IS_2	11-22kVBULKOIL_IS_2	OLX3	1982	Replace switchboard	Entire 11kV GEC OLX switchboard
INNER HARBOUR ZS, 11kV, No 2/3 Section	177362	11-22kVVACUUM_IS	3AF1722	1981	Vacuum trucks	Trucks for 15 Siemens 3AF1721 CBs
INNER HARBOUR ZS, 11kV, No 1/2 Section	177361	11-22kVVACUUM_IS	3AF1722	1981	Vacuum trucks	Included in the above - additional funding will be required to complete all CBs in the switchboard

Appendix C – Summary of key risk assessment variables and assumptions

All monetary values are indexed from $FY22 to $FY25 before being used in the cost benefit assessment unless noted otherwise.

General variables and assumptions

Parameter	Value	Description/justification	Source/assumptions
Population	4,487	Number of circuit breakers in service in Endeavour Energy's network	Ellipse database. Current to October 2021. Asset type CB.
Annual conditional failures	0	Conditional failure is not defined in EE standards. Decisions re conditional replacement are made by engineering analysis based on failure of routine diagnostic test results. No record of conditional failure based replacements.	Ellipse defect workorder records
Annual functional failures	0	Functional failures range from failure to open, which may cause reliability and financial impacts, failure to close, which may or may not have reliability impacts, to a destructive failure due to moisture ingress, loss of insulation gas or oil, wear or misalignment of contacts etc	EE outage management system (OMS), Ellipse workorder records and anecdotal information. Note – little correlation between OMS records of incidents and WO for attending to the incidents
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	FY25	All investments for budgeting purposes are expressed in real FY25 dollars	For inclusion into the FY25 program after optimisation
Calculation horizon	170 years	The timeframe over which the cost-benefit analysis is performed	Risk-based methodology V6.0 algorithm
Maintenance costs	Varies	All CBs 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. Costs are counted for the five-year period from 2017 – 2021 inclusive and averaged to give an annual value. The value is used to adjust the calendar age of the asset to give a "conditional life" as a surrogate for a health index for each asset. The economic value of SF6 leaks is calculated on an annual basis where applicable but is currently not included in the assessment due to there not being an agreed value for this within the Australian electricity industry Maintenance costs are censored if the issues is rectified through a refurbishment or major maintenance intervention. Once off repair costs generally censored to reflect the correction of an initial problem/SF6 leak if the maintenance costs do not continue after the intervention. This assessment is carried out manually.	Ellipse workorders up until October 2021.
Planned intervention costs – circuit breaker replacement	221,000	132kV and 66kV outdoor, replaced with dead tank CB from current supply contract	Provided by Substation Design based on previous projects, indexed at 2.5% pa to $FY25
	213,224	133kV and 66kV GIS CB – assuming it can be replaced like for like. Not material in the short term due to the young age of the GIS equipment	Provided by Substation Design based on previous projects, indexed at 2.5% pa to $FY25

Parameter	Value	Description/justification	Source/assumptions
	7,216,000	132kV and 66kV SF_6 switchboard – replace with GIS. Unique cost estimate based on available space for replacement equipment. Applicable only to Hazelbrook and West Pennant Hills ZS 66kV switchboards.	A specific estimate by Substation Design for Hazelbrook ZS switchboard replacement
	221,000	33kV outdoor – replaced with 33kV dead tank CB from current contract	Provided by Substation Design based on previous projects, indexed at 2.5% pa to $FY25
	374,000	33kV installed in a chamber in a transmission substation – replaced with 33kV dead tank CB from current contract. Includes additional connection works compared to the outdoor variant	Provided by Substation Design based on previous projects, indexed at 2.5% pa to $FY25
	2,585,000	33kV oil switchboard – replaced with a 33kV vacuum switchboard from the current contract. Replacement cost is per section of busbar. Typically 2 bus sections and $1,2000,000 per section escalated to $FY25	Generalised planning estimates based on previous switchboard replacement projects (eg South Wollongong ZS 33kV switchboard)
	1,008,000	Aged 33kV SF_6 switchboard - replaced with a 33kV vacuum switchboard from the current contract. Replacement cost $1,000,000 - $1,2000,000 depending on the number of CBs. Eg Bossley Park 33kV escalated to $FY25 = $1,008,000	Generalised planning estimates based on previous switchboard replacement projects (eg South Wollongong ZS 33kV switchboard) and developed in conjunction with Engineering Delivery
	137,000	Modern 33kV in modern switchboard – replace just the CB providing the parts remain available	Provided by Substation Design based on previous projects, indexed at 2.5% pa to $FY25
	197,000	11kV outdoor CB – replaced with 11kV (or 33kV) dead-tank CB	Provided by Substation Design based on previous projects, indexed at 2.5% pa to $FY25
	46,000 80,000 per truck	11kV oil CBs in a switchboard – replace CB trucks to extend the life of the switchboard. Reyrolle and Westinghouse replacements are $46,000. Other types are $80,000 on average.	Estimate from Engineering Delivery based on previous and ongoing CB truck replacements
	2,585,000	11kV GEC OLX CBs in a switchboard – replace with new vacuum switchboard. Locations are Kentlyn, Macquarie Fields and North Wollongong ZS	Generalised planning estimates based on previous switchboard replacement projects (eg Blaxland, Horsley Park, Kellyville, North Rocks and Port Central 11kV switchboards) and developed in conjunction with Engineering Delivery
	80,000 per truck	11kV SF_6 CBs in aged switchboard – replace with vacuum trucks. Trucks are custom made by GFF. Development costs and risks are incorporated into the truck costs. An alternative is whole switchboard replacement – but issues with available space and maintaining security of supply during the works is an issue which favours truck replacement.	Estimate from Engineering Delivery based on ongoing works for other CB truck replacements by Supplier GFF
Reactive intervention	Various	For outdoor CBs the costs will be similar to Proactive intervention but with modest additional clean-up and investigation costs. Oil switchboards will incur significant clean up and investigation costs. The generalised value is $780,000 (indexed to $FY25) The failure of an oil CB in a switchboard or an SF_6 or vacuum CB in an aged switchboard without current standard of bus partitioning and arc-fault venting will pollute the entire switchboard with corrosive soot and force the replacement of the entire switchboard. The failure of an SF6 or vacuum CB in a modern switchboard will only require the replacement of the CB truck or the CB panel itself	Generalised estimates based on experience of outdoor switchgear oil and SF_6 failures and indoor oil switchboard failures
Failure modes - Conditional	Various	• High contact resistance which cannot be sufficiently improved by dressing the contacts;	Routine preventative maintenance test results as per SMI 100, SMI 200 and SMI 210

<table>
<tr><th>Parameter</th><th>Value</th><th>Description/justification</th><th>Source/assumptions</th></tr>
<tr><td></td><td></td><td>Low insulation resistance which cannot be corrected;
High bushing DDF which cannot be addressed through replacement of the bushings;
Repeated failure to operate which cannot be corrected by maintenance; and
Oil or SF_6 gas leaks which become excessive and cannot be adequately managed through scheduled top-ups.
Other maintenance issues which cannot be addressed
Conditional failure is not specifically defined but is assessed by Asset Performance based on information provided by the Regions. In the past, asset condition and performance data has been used to assign a health index which has informed the replacement priorities for CBs. This system was manual and performed on a case by case basis and therefore has not been used in this assessment.</td><td>Routine visual inspection and thermo-vision tests as per SMI 140
Special diagnostic test results
Special investigations</td></tr>
<tr><td>Failure modes - functional</td><td>Various</td><td>Failure to operate when required, leading to loss of supply;
Failure to clear a fault, leading to the destructive failure of the circuit breaker;
Failure of insulation, leading the destructive failure of the circuit breaker.</td><td>The functional failure modelled in this assessment assumes a damaging failure which is not repairable and results in the CB being replaced (providing its service is still required)</td></tr>
<tr><td>Asset age</td><td>Specific to each CB</td><td>Calendar age based on the CB in-service date compared to the year of assessment (2022)
Youngest CB age = 0 years
Oldest CB age = 61 years</td><td>Data from Ellipse, cleansed using a range of sources including: Known contract dates from manual s and records, serial number sequences, establishment dates of the host substations, dates of significant refurbishment works, dates of adjacent equipment of the same type.</td></tr>
<tr><td>Conditional age</td><td>Varies</td><td>Adjustment to the calendar age to reflect the condition of the asset to allow the Weibull function to more accurately assign PoF.
Based on CBM and F&E maintenance costs over the past 10 years, averaged to an annual value.
Range of:<table><tr><th>Maintenance costs Pa</th><th>Adjustment to "In-service date" (years)</th></tr><tr><td>$ -</td><td>-3</td></tr><tr><td>$ 100</td><td>0</td></tr><tr><td>$ 200</td><td>2</td></tr><tr><td>$ 400</td><td>4</td></tr><tr><td>$ 800</td><td>6</td></tr><tr><td>$ 1,600</td><td>8</td></tr><tr><td>$ 3,200</td><td>10</td></tr></table></td><td>Estimates which give a reasonable spread in PoF for CB of similar calendar ages but in variable condition.</td></tr>
</table>

Weibull failure probability parameters

Parameter	Value	Description/justification	Source/assumptions
α (Alpha)	Varies for the range of CB types. Refer table below	The "scale" parameter used for calculating probability of failure. This, along with the shift variable γ sets the mean time to failure for the asset	Failure data is sparse and not helpful. Estimated to give a reasonable looking MTTF, which range from 46 years for an 11kV SF_6 switchboard comprised of 12 CBs to 96 years for an individual 11kV bulk oil CB These values provide reasonable correlation with the actual very low annual failure rates being experienced and address the difference in probabilities of failure for individual assets which are generally independent of each other and the older style switchboards where the failure of any one CB in the switchboard will cause the end of life for the entire switchboard. The PoF of the switchboard in these cases is an aggregation of the PoF of each CB plus each section of busbar and is 1 – the probability of each element of the switchboard surviving the year. Refer table below.
β (Beta)	Various for the range of CB types. Refer table below	The "shape" parameter used for calculating probability of failure function. Sets the shape of the distribution of failure ages in a population of assets.	The generalised wear-out function shape for a normal distribution is 3.6. Adjusted values have been applied to switchboards to match the combined failure probabilities of the constituent CBs and busbars. Refer table below.
γ (Gamma)	Various for the range of CB types. Refer table below	The "shift" parameter which gives a failure-free period at the start of the asset's life.	Estimated values applied to reflect the very low number of functional failures recorded for the fleet of assets to date, then a forecast an increase in failures as the assets become aged and wear out. Refurbished switchboards (with CB truck replacements) are represented in the model with the same Weibull function but a reduced shift parameter to reflect the conditional age of the switchboard after refurbishment. $\text{Shift}_{\text{refurbished}} = 30_{\text{(initial)}} - 50_{\text{(years at refub)}} = -20$ years

CB asset type	Weibull shape parameter	Weibull scale parameter (yr)	Weibull shift parameter (yr)	MTTF (yr)	Comments
11-22kVBULKOIL_IS_1	3.8	51.6	25	72	emulates the combined PDF of an 11kV oil switchboard with 1 BS and 4 CBs
11-22kVBULKOIL_IS_2	3.9	38.8	25	60	emulates the combined PDF of an 11kV oil switchboard with 2 BS and 13 CBs
11-22kVBULKOIL_IS_3	3.9	34	25	56	emulates the combined PDF of an 11kV oil switchboard with 3 BS and 21 CBs
11-22kVBULKOIL_O	3.6	75	28	96	
11-22kVSF6_IS	3.6	70	15	78	
11-22kVSF6_O	3.6	70	15	78	
11-22kVSMALLOIL_O	3.6	60	10	64	
11-22kVVACUUM_IS	3.6	65	10	69	
11-22kVVACUUM_IST	3.6	80	-20	52	Weibull for old air-insulated busbars (3.6/80/30) shifted for 50 years nominal age at installation of trucks
11-22kVVACUUM_O	3.6	60	10	64	
132-66kVSF6_IS	3.6	55	15	65	
132-66kVSF6_O	3.6	55	15	65	
132-66kVSMALLOIL_O	3.6	55	15	65	
132-66kVVACUUM_O	3.6	55	6	56	
33kVBULKOIL_IC	3.6	60	25	79	
33kVBULKOIL_IS_2	3.6	41	25	62	emulates the combined PDF of an 33kV Boil switchboard with 2 BS and 6 CBs
33kVBULKOIL_O	3.6	60	25	79	
33kVSF6_IC	3.6	60	10	64	
33kVSF6_IS	3.6	60	10	64	
33kVSF6_O	3.6	60	10	64	
33kVSMALLOIL_IS_2	3.6	38	15	49	emulates the combined PDF of an 33kV Soil switchboard with 2 BS and 5 CBs
33kVSMALLOIL_O	3.6	50	15	60	
33kVVACUUM_IC	3.6	60	10	64	
33kVVACUUM_IS	3.6	60	10	64	
33kVVACUUM_O	3.6	60	10	64	
AuxiliarybusbarCB_IA	3.6	60	10	64	
InternalcapacitorCB_IA	3.6	60	10	64	
SubstationLBS-REC_O	3.6	60	10	64	
11-22kVSF6_IS_2	3.6	34.5	15	46	emulates the combined PDF of an 11kV SF6 switchboard with 2 BS and 12 CBs
33kVSF6_IS_2	3.6	38	10	44	emulates the combined PDF of a 33kV SF6 switchboard with 2 BS and 5 CBs
132-66kVSF6_IS_2	3.6	38	10	44	use 33kV SB Weibull for starters

Safety risk inputs

Risk is to workers. Nil impact on the public.

All monetary values are indexed from $FY22 to $FY25 before being used in the cost benefit assessment

Parameter	Value	Description/justification	Source/assumptions
Value of a fatality	$5,100,000	Value of statistical life (VoSL)	EE Copperleaf Value Model – based on Office of Best Practice Regulation published values
Value of a serious injury	$2,249,000	44.1% of VoSL	GNV1119
CB failure results in injury - LoC	2%	Likelihood of person being in the vicinity of the CB	Estimate based on generalised visit to substations by maintenance and other workers
	0 - 25%	Likelihood of causing a fatality if someone is present: 0% for SF6 or vacuum CB 10% for oil CB in the switchyard 25% for oil CB in control building	Estimate based on inspections of the aftermath of asset failures in switchyards and control buildings
	0 – 75%	Likelihood of causing a serious injury someone is present 0% for SF6 or vacuum CB 30% for oil CB in the switchyard 75% for oil CB in control building	Estimate based on inspections of the aftermath of asset failures in switchyards and control buildings
	10%	Likelihood of causing a minor injury someone is present 10% for SF6 or vacuum CB	Estimate based on inspections of the aftermath of asset failures in switchyards and control buildings
		Number of persons likely to be present is 2, out of a population of 50 likely to be exposed	Estimate based on usual size of work teams and the population of workers frequenting substations
Safety disproportionate factor	3	Reflects the weight placed on safety by society	The minimum value from GNV1119 based on the low likelihood of fatality
Safety risk CoF	Varies	The overall safety risk CoF: $3,223 for vacuum and SF_6 CBs $47,389 for oil CBs outdoors $355,419 for oil CBs indoors	Product of the above values for each type and location of CB

Bushfire risk inputs

Parameter	Value	Description/justification	Source/assumptions
			Nil for CB. All effects are contained within the substation boundaries

Environmental risk inputs

Parameter	Value	Description/justification	Source/assumptions
Environmental – CoF – SF_6 gas	$524/kg	Economic value of SF6 gas discharge to atmosphere. Global warming potential - 22,800 $CO2_e$ Value of carbon - $23/tonne For CBs containing SF_6 gas	Values of consequence are estimates based on published data. Global warming potential of SF_6 – published value Value of carbon credits published by Reputex Energy August 2021
Leakage rate	Varies	The loss of SF_6 through leakage on an annual basis. Considered to be an annual service cost for the asset **Currently not used**	SF_6 bottle weight logs provided by the Regions. Hard copy and "Bottle Editor" application. Values over three years and averaged to an annualised value. The data is censored if the leak has been succesfully repaired – as advised by the Regions or evidenced through the pattern of Ellipse workorders and/or leak rates
Weight of SF_6	Varies	The weight of SF6 in kg used in each CB Considered to be an environmental CoF	Ellipse data, "Bottle Editor" application SF_6 inventory, equipment manuals and advice provided by Engineering Delivery
Environmental - LoC	100%	Likelihood of the above environmental impact occurring CB failure – for CBs with SF_6 used for insulation or arc-quenching	LoC assumed to be = 1 for SF_6 CBs **Note that this variable is currently not used due to their not being an agreed value for the economic impact of SF_6 in the Australian electricity industry**
Disproportionate factor	0 -10	To reflect the value of reducing SF6 gas emissions	To be set by Endeavour Energy in concert with the AER **Currently set to 0 so that this factor is not included in the cost-benefit assessment as no value is currently set**
Oil leaks	Varies	Leaks and or loss of oil from an oil CB on failure	Currently not considered to be material as environmental impact is minimal and confined to the switchyard/control building

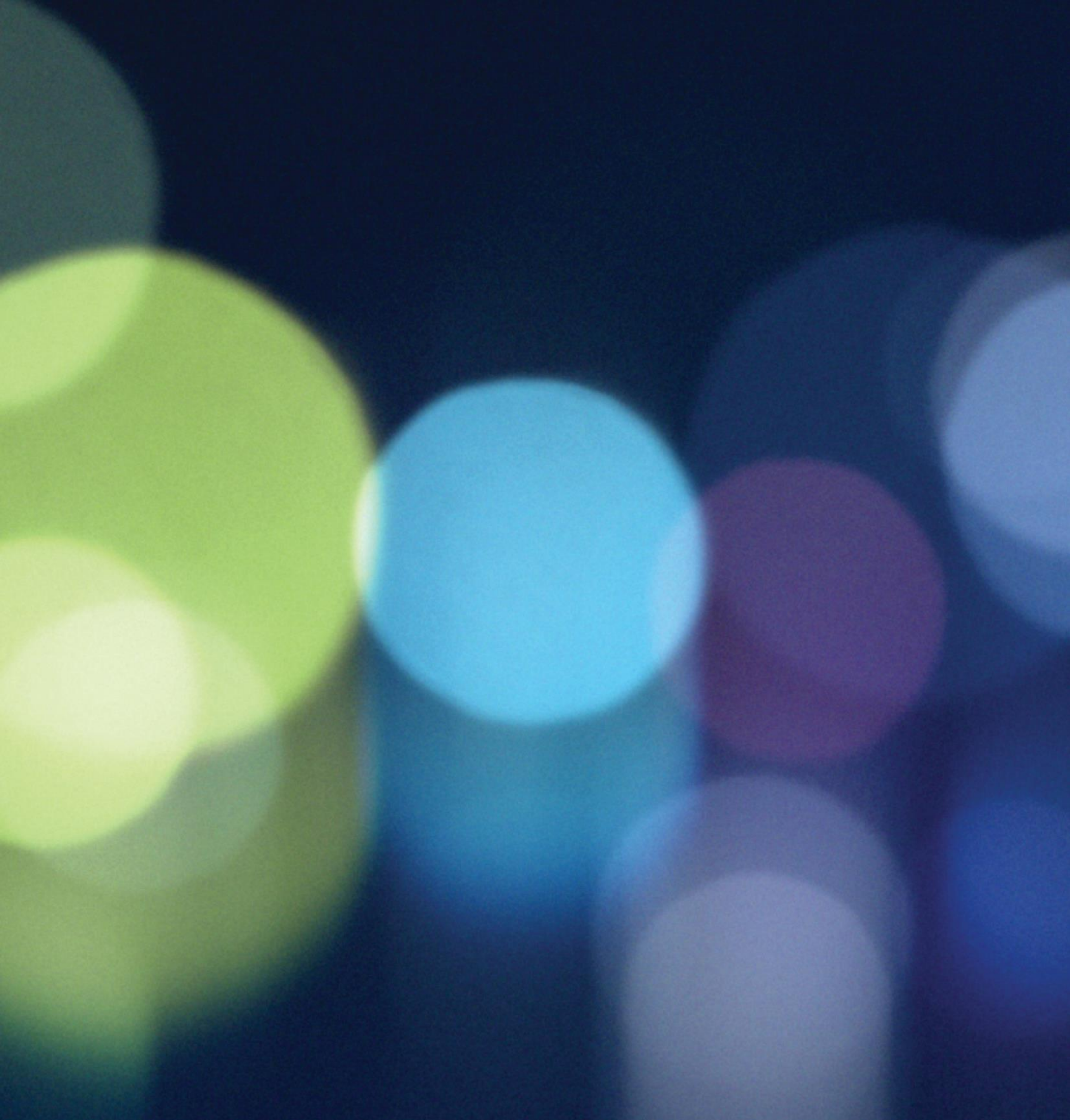
Reliability risk inputs

Parameter	Value	Description/justification	Source/assumptions
Loss of supply to customers - LoC	1% generally 33 - 100% for specific cases	1% likelihood of loss of load when N-1 supply security is available The likelihood of loss of load depends on the position of the CB within the substation, the number of busbar sections and the presence of bus-section circuit breakers. Varies from 33% loss of load where three automatically bus-sections are available to 100% where only one is available	RisCAT - 1% likelihood the alternate supply path will not be available due to maintenance, or failure. Ellipse data and count of bus-section CBs at each voltage in each substation in FME to resolve the likely level of supply security for each CB and the location of switching to automatically restore supply after a CB failure. Verified by review of specific sites in SOPS
Load impacted	Specific to each substation/switching station	The summer maximum demand of the substation at 50% probability of exceedance	2021 Summer Maximum Demand planning report
Load factor	70%	Load assumed to be lost is 70% of the summer maximum demand value for the supplied substation(s)	Source – studies of network faults by Protection Manager.
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

Parameter	Value	Description/justification	Source/assumptions
Duration of interruption	4 hours	4 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

Financial risk inputs

Parameter	Value	Description/justification	Source/assumptions
Financial general - CoC	$20,000	Switching to restore supply/supply security, clean-up, any temporary diversion works, investigation, media management costs	Estimate, based on typical clean-up and investigation costs
Financial general - LoC	100%	Likelihood of general financial risks being realised on failure	Will always be realised to an average extent.
Financial – damage to buildings – CoC	$700,000	Recovery costs for an oil CB failure in a control building – 100% LoC for oil switchboard 0% LoC for SF_6 and Vacuum	Estimate based on experience of past oil switchboard failures
	$300,000	Provision of load support by temporary switchboard 10% LoC for oil switchboard 0% LoC for SF_6 and Vacuum	Estimate based on experience of past oil switchboard failures
	$50,000	Provision of load support by generators 25% LoC for oil switchboard 0% LoC for SF_6 and Vacuum	Estimate based on experience of past oil switchboard failures
	$100,000	Recovery costs for an oil CB failure in a transmission substation chamber – 100% LoC for oil switchboard 0% LoC for SF_6 and Vacuum	Estimate based on experience of past oil switchboard failures
	$150,000	Recovery costs for damage to adjacent bay equipment for outdoor CB 33% LoC for oil CB 0% LoC for SF_6 and Vacuum	Estimate based on experience of past oil switchboard failures
Reactive replacement costs	Varies	Reactive replacement costs generally equal planned replacement costs except that whole switchboard replacement will be required for all oil switchboards and older SF_6 and vacuum switchboards without current standard CB and busbar chamber barriers and arc-fault ducting and venting	Estimate based on experience of past oil switchboard failures



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