



Rural Feeder Protection

Name changed from "Country Protection Compliance"

Business Case

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SA Power Networks

www.sapowernetworks.com.au

Business Case – Rural Feeder Protection

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1. EXECUTIVE SUMMARY

The Rural Feeder Protection (RFP) initiative is a **\$7.11 million** program developed to mitigate and maintain the network risks associated with inadequate backup protection within the 19kV network in the rural areas. This program is a continuation of a program started in 2013 and solutions within this document are proposed to be implemented over the next regulatory control period, 2020/21 to 2024/25.

SA Power Networks developed Risk and Cost Benefit Analysis (CBA) models as a part of this program to determine the eligibility of each feeder to be included in the overall program. The Risk model calculates the risk carried by every 19kV feeder whilst the Cost Benefit Analysis (CBA) model determines the net economic value of protection solutions deployed on to the affected feeders. This program only includes solutions for the inadequately protected feeders that were found to be economically viable, i.e. total risk benefits and benefits to the customer exceed initial solution cost in present value terms.

It is estimated that over the course of 25-year asset life, the total benefits are in the order of **\$10.28 million** with a Net Cash Flow of **\$3.17 million** (exclusive of discount rates). In addition, it is also estimated that the total 'at risk' Value of Customer Reliability (VCR) that is avoided due to the implementation of this program is **\$1.09 million** over the course of 25 years.

The 11kV feeders that are supplied from transformers of size 5MVA or below in the rural areas have been excluded from the program for the 2020/21 to 2024/25 regulatory period. These were excluded as the total risk and VCR benefits are low and is not justifiable for the initial solution costs. These feeders shall continue to remain in the watchlist for the foreseeable future until risks have escalated and/or newer and economically viable solutions become available.

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2. INTRODUCTION

The Rural Feeder Protection (RFP) program is a continuation of an established program that is aimed to address backup protection inadequacy in the rural areas. As a part of this program, the highest risk rural feeders have been actioned using proven modern protection solutions since 2013. For the regulatory period 2020-2025, SA Power Networks has acknowledged the comments made by AER on the draft submission.

The Risk and Cost Benefit Analysis models developed by SA Power Networks is presented in the resubmission to demonstrate the prudent and efficient selection and inclusion of rural feeders in the RFP program. Modern and cheaper protection technology is now available on the market, since our draft submission, and is adopted in the program to reduce the overall cost and to improve the efficiency of the program. The evidence of asset damage due to the primary protection failures are presented in the resubmission document.

3. BACKGROUND

It is standard industry practice to have adequate over-reach, or backup, protection throughout the high voltage network. If the primary protection device fails, upstream protection is designed to provide a failsafe and will operate to clear a fault. This ensures that faults on the network are not permitted to persist, uncontrolled even in the event of an equipment failure. This is the general design philosophy used throughout the network.

There are very low fault current levels across SA Power Network's rural distribution network, as a result of the rated capacity of the network (there are lower energy flows). With low fault current levels in rural networks, upstream protection cannot provide backup or overreach protection in the event of a failure of the primary protection – [REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

In rural areas of the network, SA Power Networks utilises one set of electromechanical devices (i.e. Hydraulic Reclosers) for SWER feeders. [REDACTED]

[REDACTED]

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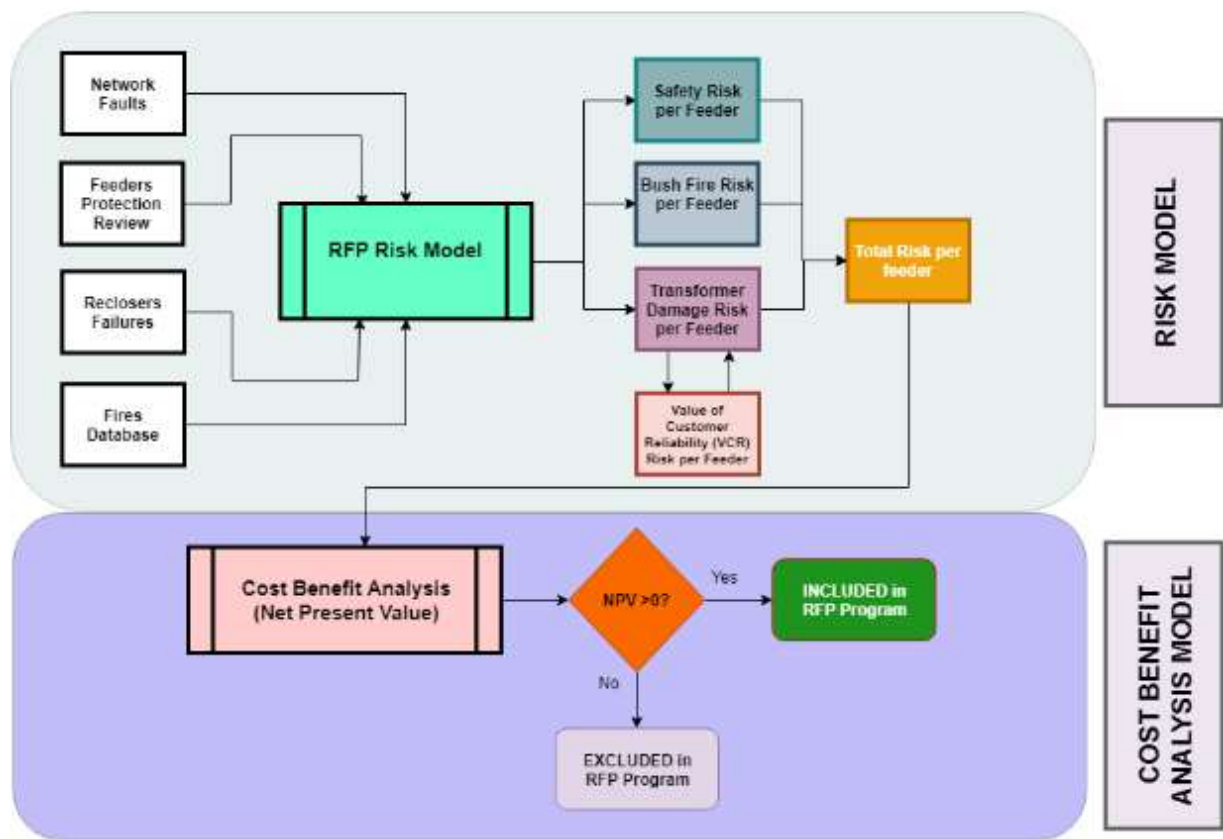


Figure 1: The RFP Risk & CBA Model

6. RISKS

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]

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The total risk carried by each feeder is the sum of the following:

- **Safety risk**

[Redacted]

- **Bushfire risk**

[Redacted]

- **Transformer damage risk**

This is the risk of permanent transformer damage due to an uninterrupted fault and the subsequent prolonged outage.

- **Value of Customer Reliability (VCR) Risk**

This is the economic risk applied due to the transformer damage resulting in a prolonged outage (refer to section 6.3.2).

$$Total Risk = Safety Risk + Bushfire Risk + Transformer Damage Risk$$

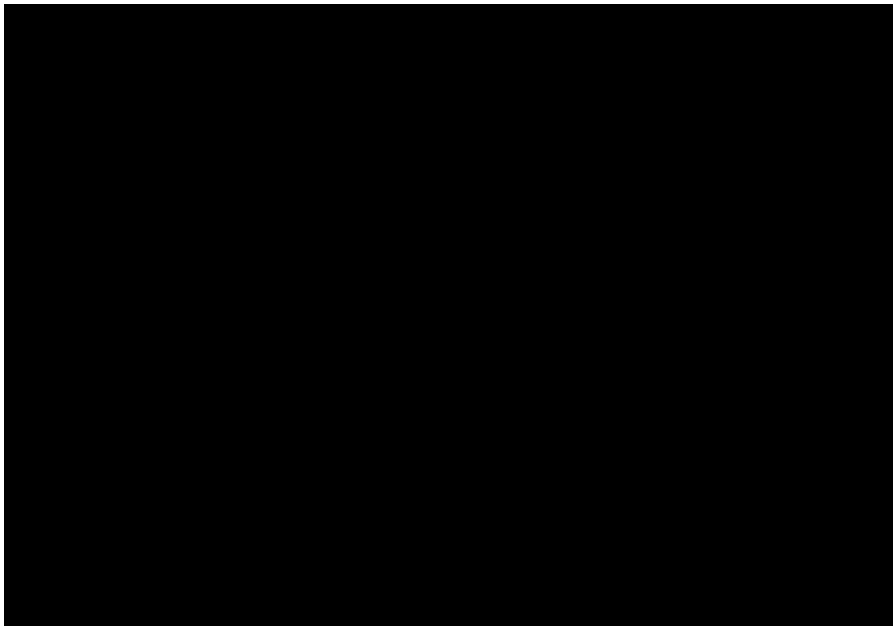
Equation 1: Total Risk

Each risk is calculated as the product of the likelihood of the event occurring and the consequence of that event (refer to Appendix 7 for breakdown of risk calculations). Figure 3 below shows the overall economic risk composition on the 19kV network, with the transformer damage risk being the highest contributor.

$$Risk = Probability \times Consequence (\$)$$

Equation 2: Risk

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6.1 Safety Risks

On average, SA Power Networks experiences 29 safety related incidents per year from equipment such as excavators and EWPs, coming into contact with HV conductors on the 19kV network. The longer the fault area remains energised, the higher the probability that a person in close proximity to the fault could come into contact with energised assets. The safety risk formula is as follows:

$$\textit{Safety Risk} = \textit{Death Risk} + \textit{Injury Risk}$$

Equation 3: Safety Risk



The RFP program aims to minimise the safety risk of all the selected feeders with the priority being the feeders with highest risk.

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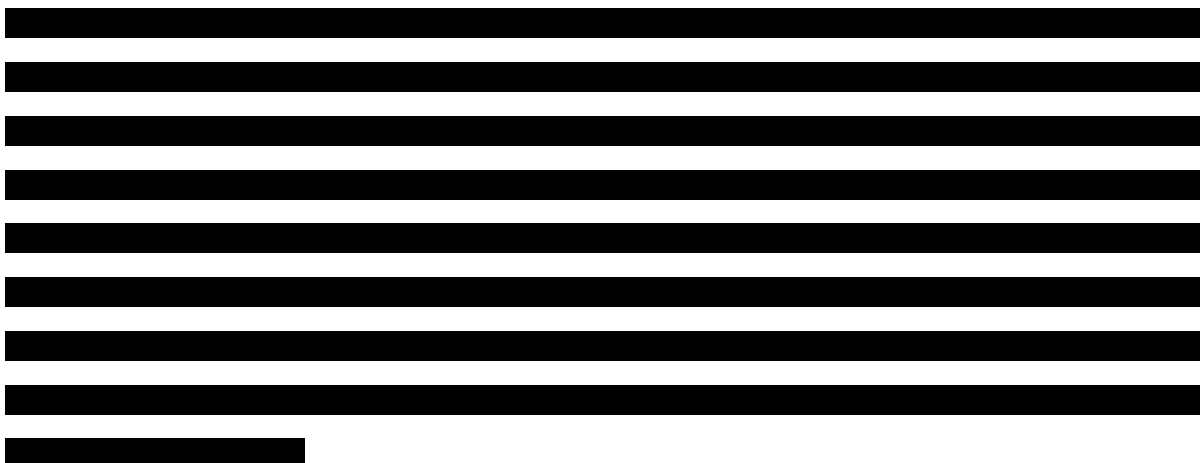
6.2 Bushfire Risks

The RFP program addresses the consequential risk of starting a bush fire as a result of equipment being damaged due to uncleared faults. There is clear historical precedence where electrical infrastructure has been involved in bushfire ignitions, such as Ash Wednesday in 1983, and Black Saturday in 2009. The RFP model does not over-lap in any way with the SA Power Network’s Bushfire Management program. The unique features of the RFP are:

1. The RFP program focuses on prevention of potential bushfire starts caused by the **primary protection failure and subsequent equipment damage**.
2. The RFP program targets feeders located in **both** Medium Bush Fire Risk Areas (MBFRA) **and** High Bush Fire Risk Areas (HBFRA).

The two models utilise the common base data such as economic cost, probability of ignition model, fire ban period and fire start record in the model development (refer to Figure 18 in Appendix 7 for comparison).

6.3 Transformer Damage Risks



$$\text{Transformer Damage Risk} = \text{MAJOR Damage Risk} + \text{MINOR Damage Risk}$$

Equation 4: Transformer Damage Risk

6.3.1 Transformer damages due to uncleared faults

Based on the transformer protection curve published by IEEE (Category 1 IEEE C37.91), it is suggested that the maximum allowable time is between **3 seconds to 32 seconds** to prevent the isolation transformer damage on our network (for 150kVA rated transformer and fault currents between 50A to 160A). If existing primary protection fails and if there is no backup protection, then the isolation transformer will fail if the conditions for transformer damage shown in Figure 4 are exceeded. The RFP program aims to achieve backup protection of **2 seconds** or less, in the event of primary protection failure, to avoid transformer damage (see Figure 4).

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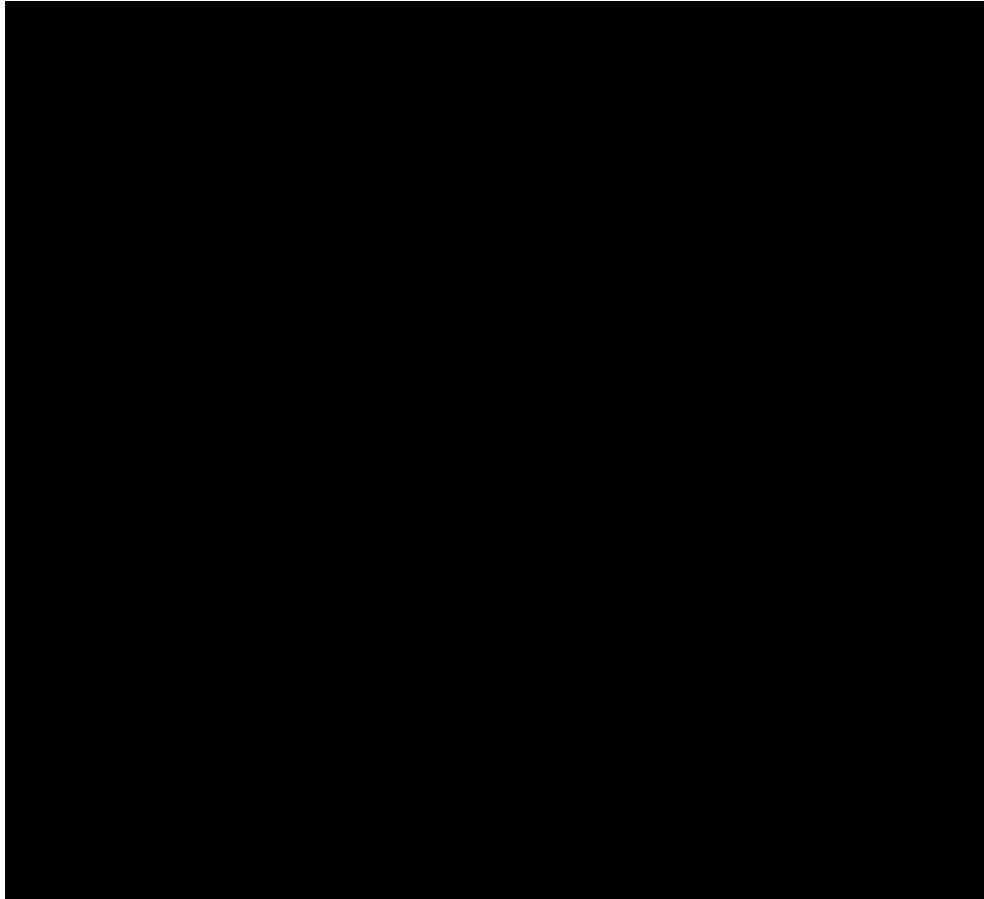
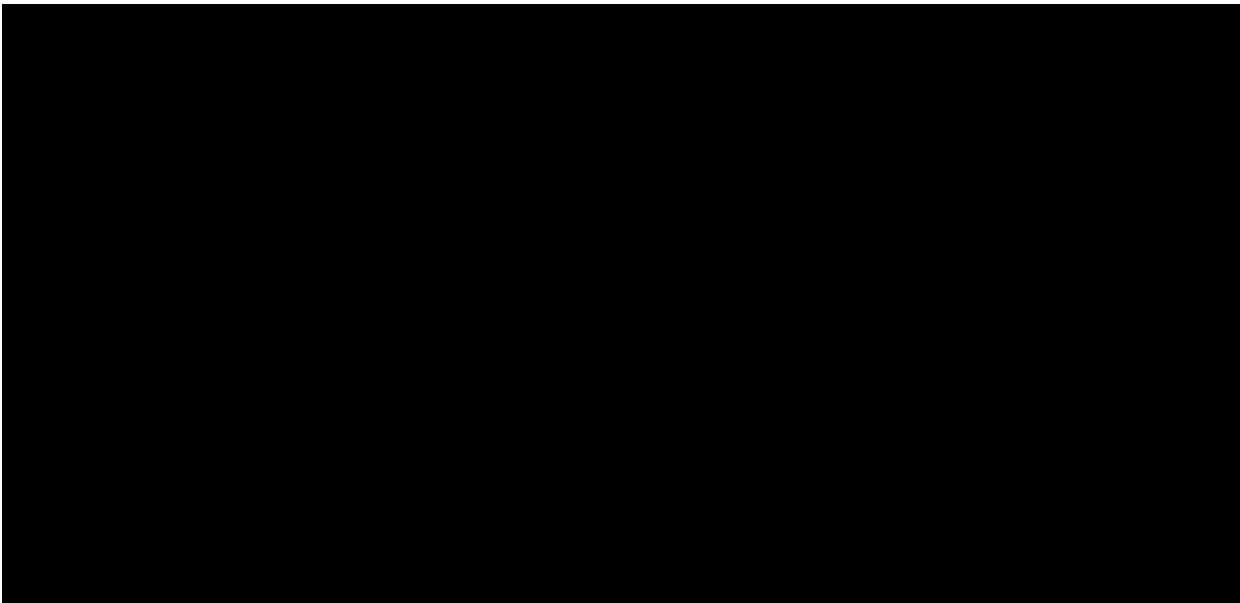


Figure 4: Transformer Damage Curve vs Backup Protection Clearing Time

The sequence of events for a transformer failure resulting from a primary protection device failure is shown in the diagram below (read right to left):



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[REDACTED]
[REDACTED] (see table below). [REDACTED]
[REDACTED]
[REDACTED] The findings from
the protection review can be found in Appendix 6.

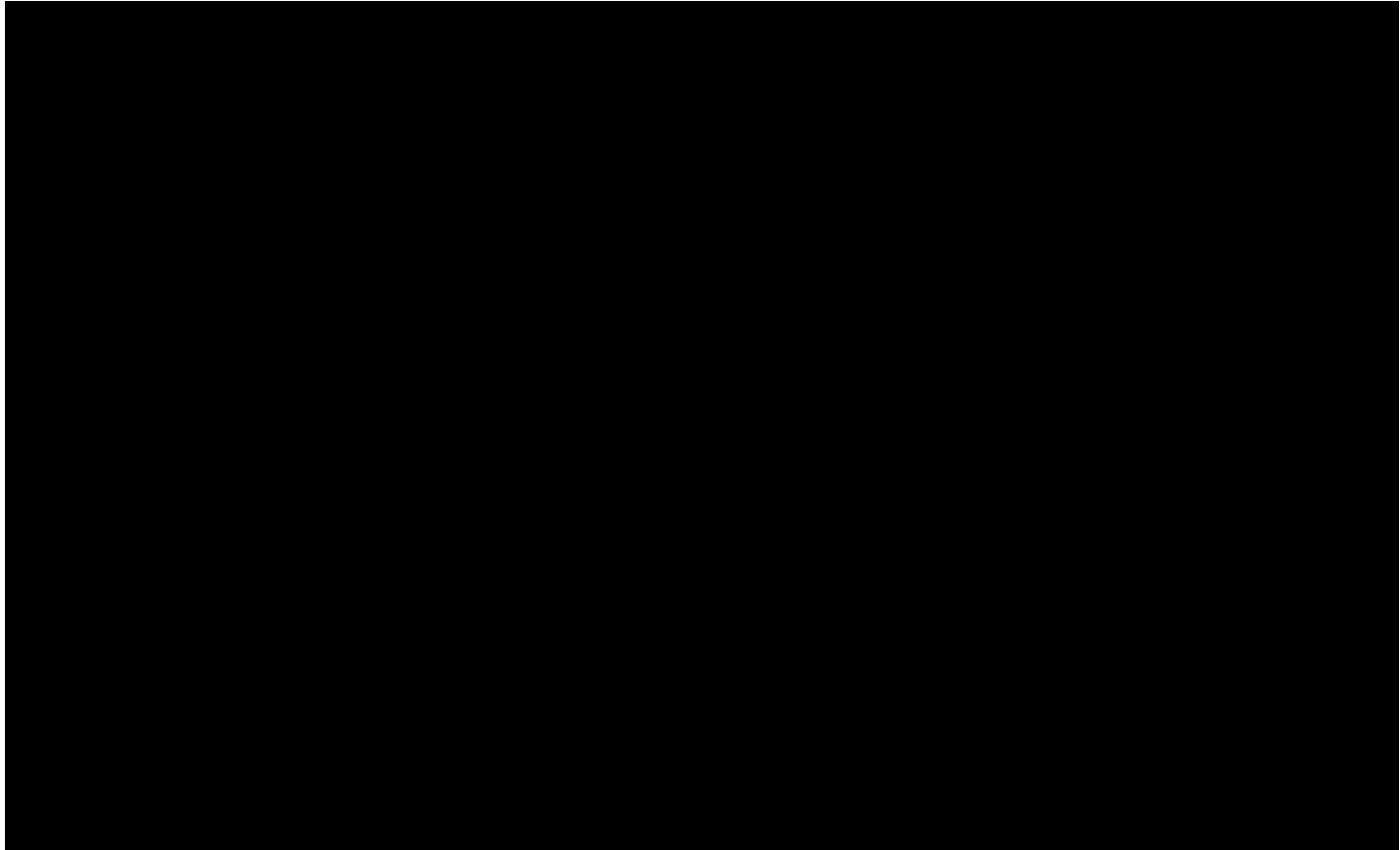


Table 1: The incidents of assets being damaged due to the existing backup protection issues in rural areas.

6.3.2 Value of Customer Reliability (VCR)

As defined by AEMO, the Value of Customer Reliability (VCR) represents a customer’s willingness to pay for the reliable supply of electricity. This value is used in the risk calculation associated with every feeder in the event of Major or Minor transformer damage. In the event of such damage, the customers on that feeder would suffer from a power outage for a duration of up to 12 hours, which causes potential economic losses to the customer (i.e. unable to run businesses). The VCR benefit of each feeder is then calculated as a subsequent risk based on an outage of 12 hours for major transformer damage and an outage of 4 hours for minor transformer damage. It is also estimated that the total ‘at risk’ Value of Customer Reliability (VCR) that is avoided due to the implementation of this program is **\$1.09 million** over the course of 25 years.

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7. PROTECTION SOLUTIONS

The RFP program proposes to install additional protection device(s) to ensure that all credible faults, are cleared in a timely manner (2 seconds or less) by the backup protection device, when primary protection has failed. Different protection solutions have been assessed to determine the most suitable strategy using a cost benefit analysis model, including new technology to address the inadequate backup protection on the rural feeders (Refer to Section 9 for the feasibility analysis). Note that all high risk 11kV feeders have been actioned prior to 2020. The lower risk 11kV feeders will be considered beyond the 2020 to 2025 regulatory control period. The solutions and their suitability for selected 19 kV SWER feeders are further explained in Section 9.

The considered solutions and the justification for each are shown below:

Feeders Types	Solutions	Solutions Description	Justification
19kV	Solution 1	19kV Recloser* with SCADA control plus existing Hydraulic Recloser	This option is selected for feeders with higher total risks and greater customer impact. HBFRA/MBFRA feeders have the added benefit of SCADA which allows for remote operation during bushfire danger days. As demonstrated in Appendix 5, to avoid “silent” failure of electronic devices, it is highly recommended that devices are deployed with SCADA on to the field. Additional SCADA benefits include alarms sent out for device or battery failure on the new electronic device.
	Solution 2	19kV Recloser* without SCADA control plus existing Hydraulic Recloser	This option is selected for feeders with medium total risk and lower customer impact. NBFRA feeders are considered for this option as it provides no bushfire danger day benefits. The electronic device without SCADA reduces total risk but will not be reduced to the achievable minimum total risk. The number of electronic reclosers without SCADA deployed on to the network is very minimal due to the “Silent” failure nature of reclosers.
	Solution 3	Sectionalising Fuses and Settings Change	This option is selected for feeders with minimal protection inadequacy and low customer impact. The use of fuses is not recommended for feeders with higher risks and larger customer numbers due to the additional impact on customer reliability. Fuse size is carefully selected to ensure grading with existing recloser fast and slow trips to minimise fuse operations for transient faults. Operational costs such as fuse operations per year and VCR impact is considered, which makes this option less economically viable for higher risk feeders.

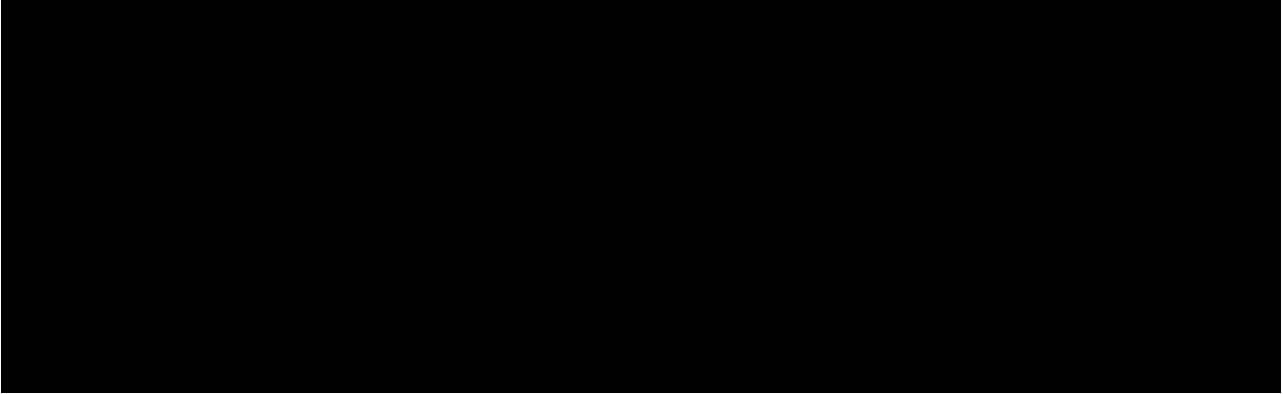
HBFRA = High Bush Fire Risk Area, MBFRA = Medium Bush Fire Risk Area, NBFRA = Non-Bush Fire Risk Area

*New low cost compact recloser

Table 2: Protection Solutions table

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The concept of the typical proposed protection solution is shown in Figure 6 below, and the primary/backup protection used is based on the selected solution. The location of the new device is dependent on the existing condition of inadequate backup protection on the feeder.



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8. COST BENEFIT ANALYSIS

The Net Present Value (NPV) of each solution investment cost determines the inclusion of a feeder in the RFP program. The feeders that can demonstrate **positive net present value** over the course of a 25-year asset life will be considered in the program. The solution that produces the highest positive NPV is selected for that specific feeder (see Appendix 3 for comparison). It is important to understand that this program cannot eliminate all the risks associated with safety, bushfire and equipment damage within the network. The program aims to mitigate and manage the risks associated with safety, bushfire and equipment damage efficiently, **for when the primary protection device has failed** to operate for a fault on the network.

8.1 Solution Benefits

Each solution considered in the RFP program has their own benefits as well as operational costs. Refer to Appendix 9 for all risk benefits across all feeders and comparison of Net Present Value across all solutions. Solutions are carefully selected based on the existing risk of the feeder and taking operational costs and other benefits into account. Note that if the considered solutions are not implemented, significant risks remain on the network.

8.2 Net Cash Flow

The overall net cash flow of the program is shown in Figure 8. It demonstrates that the total benefit of the program in the end of investment period is **\$10.28M** with the initial investment cost of **\$7.11M**. The net benefit of the program is then **\$3.17M** (before discount rate of 2.63%).

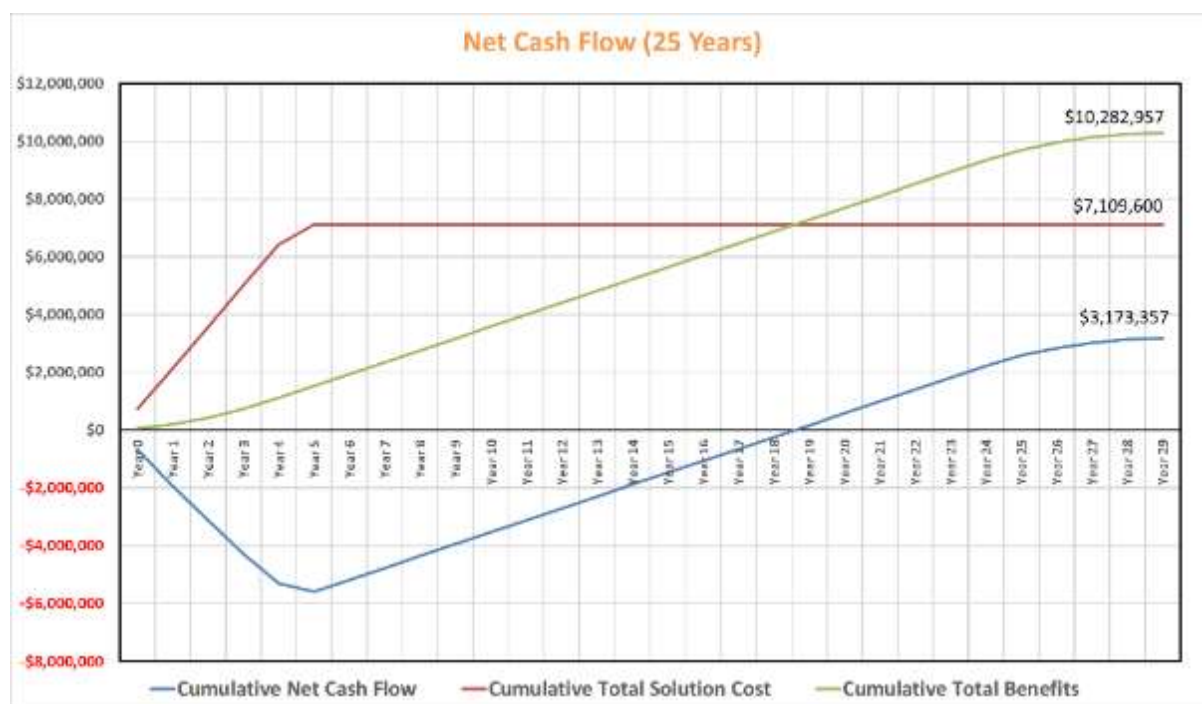


Figure 7: Overall NPV of the FRP program (ex. Discount rate)

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9. OPTIONS ANALYSIS

Various options have been considered to address the protection inadequacy in rural feeders. These options are presented below. SA Power Networks recommends **Option 2** to be the most viable and effective strategy.

Option 1 – Abolish Existing Program (NOT recommended)

The engineering analysis showed that transformer failure in our network is expected if the fault current clearing times are not met. This is not considered to be acceptable for the known risk of energised assets causing preventable harm. The analysis also showed the safety and bushfire risks associated with primary protection failures on the rural network.

The project cost for this option is **\$0**.

Pros	Cons
<ul style="list-style-type: none">Nil capital expenditure but risks remain.	<ul style="list-style-type: none">Value of combined risks (safety, asset damage, etc) is significant and is avoidable.Safety of public in the event of primary protection failure. The conductors and most likely the poles at the fault location will remain live. The exposure of public to the risk is greatly increased without adequate protection.Plant damage due to slow or non-existent backup protection if the primary protection device fails to operate for a legitimate fault.

Option 2 – Protection Solutions based on Cost Benefit Analysis (Recommended)

This is effectively a hybrid of options 1, 3 and 4, where the optimal solution for each feeder is considered on individual merit (on a per feeder basis). Feeders that do not show positive outcome in the NPV calculation for any solution will be excluded from the program - option 1 (Refer Appendix 9). The excluded feeders shall continue to remain on the watchlist and will be carefully monitored for the escalation of any risks, or as new economical protection solutions are available. Compact 19kV Recloser and fuse solutions will be deployed (option 3 and 4, below) where these solutions offer the highest NPV return on investment for the individual feeder.

Each solution that is part of the program is carefully selected to ensure that existing quality of supply is not impacted, or new long-term problems are not introduced. The estimated cost for resolving protection inadequacy of selected 19kV feeders is **\$ 7.11 million** with expected completion in 5 years

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(end of 2025). In the overall Net Cash Flow of the program depicted in Figure 7, the benefits (or risks avoided) outweigh the cost of the investment.

Pros	Cons
<ul style="list-style-type: none"> The failure of the protection equipment can be monitored to a certain degree and acted immediately (solutions with SCADA) to reduce customer and community safety risks in higher customer density areas. The damage of the plant can be significantly reduced by quicker clearing times in the case of primary device failure. The start of bushfire risk is mitigated by setting reclosers to single trip fast settings to lock out remotely during high fire danger level (FDL) days in higher customer density areas. HBFRA/MBFRA feeders are significantly benefited with this solution. The severity of the electrical injuries when primary protection fails to operate for human contact can be improved in higher customer dense areas. 	<ul style="list-style-type: none"> Capital cost. Higher maintenance cost including battery replacement maintenance (solution with electronic reclosers). Only basic low cost solutions such as fusing and minor setting changes to be applied in areas of lower risk and customer density as determined by the NPV assessment.

Option 3 – Install electronic reclosers on every affected feeder (NOT recommended – Based on NPV assessment)

Option 3 achieves full benefits by using reclosers for 11kV feeders and new low cost compact reclosers for 19kV feeders, for all feeders that have inadequate protection issues. This option will address the inadequate back up protection issue and maintain reliability of supply for regional customers, however this option requires higher capital investment. As detailed above, whilst this is not the preferred solution for all locations, there are some 19kV feeders where this solution returns the highest NPV.

Pros	Cons
<ul style="list-style-type: none"> The risk on 19kV network is reduced to the lowest possible level. Customer reliability is maintained. 	<ul style="list-style-type: none"> The cost is higher compared to Option 2. Higher maintenance cost including battery replacement maintenance (solution with electronic reclosers).

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Option 4 – Install Sectionalising or Backup Fuses (NOT recommended)

This option uses sectionalising fuses on the sections of the feeder where there is no backup protection. Though the cost is the cheapest for installation and addresses the risk, there is adverse impact on reliability of supply. Fuses will operate for transient faults – particularly lightning strikes. This solution will adversely affect reliability in regional communities and hence this option requires careful assessment before being accepted as a preferred solution. The detrimental cost to regional reliability reduces the economic benefits of this solution. As detailed above, whilst this is not the preferred solution for all locations, there are some feeders where this solution returns the highest NPV.

Pros	Cons
<ul style="list-style-type: none"> Adequate protection compliance can be achieved but in an unfavourable way Low cost of program 	<ul style="list-style-type: none"> Fuses will operate for transient faults and not reclose. Reliability impact and ongoing increase in costs each year. The amount of interruptions to regional customers will increase, especially during storms. Long restoration times since fuses cannot be remotely controlled or replaced. Result in increase of operating cost to replace fuses due to operations during transient fault and storm events. Significant customer impact to regional communities.

The pros and cons of each option is summarised in the following table:

#	Options	Cost	Advantages	Disadvantages
1	Abolish existing program	\$ 0	<ul style="list-style-type: none"> No capital expenditure 	<ul style="list-style-type: none"> Safety of public is at risk Risk of bushfire start Risk of asset damage and customer impact
2	RFP Program based on CBA	\$ 7.11M	<ul style="list-style-type: none"> Safety, Bushfire and Asset Damage risks are reduced to a manageable level 	<ul style="list-style-type: none"> Not every feeder is targeted Small customer impact
3	Full Benefits	\$ 41M	<ul style="list-style-type: none"> Lowest possible risk level Lowest customer impact 	<ul style="list-style-type: none"> Higher investment cost
4	Fuses only	\$ 0.65M	<ul style="list-style-type: none"> Low cost 	<ul style="list-style-type: none"> Severe customer impact with more interruptions and longer restoration times

Table 3: Summary of Pros and Cons of different Options

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10. PROJECT COST

Based on the model analysis, the NPV result shows that the risks of 203 SWERs can be mitigated using the proposed protection solutions, while maintaining net positive economic benefits. In the next regulatory period 2020 to 2025, a **\$7.11 million** program is required to apply protection solutions to solve protection inadequacy and manage risks on selected 19kV SWERs throughout the network. The remaining affected feeders, both 11kV and 19kV are expected to be resolved by 2030 when new economical solutions are available or if risk levels have increased in the future. Refer to Appendix 4 for the breakdown of the cost.

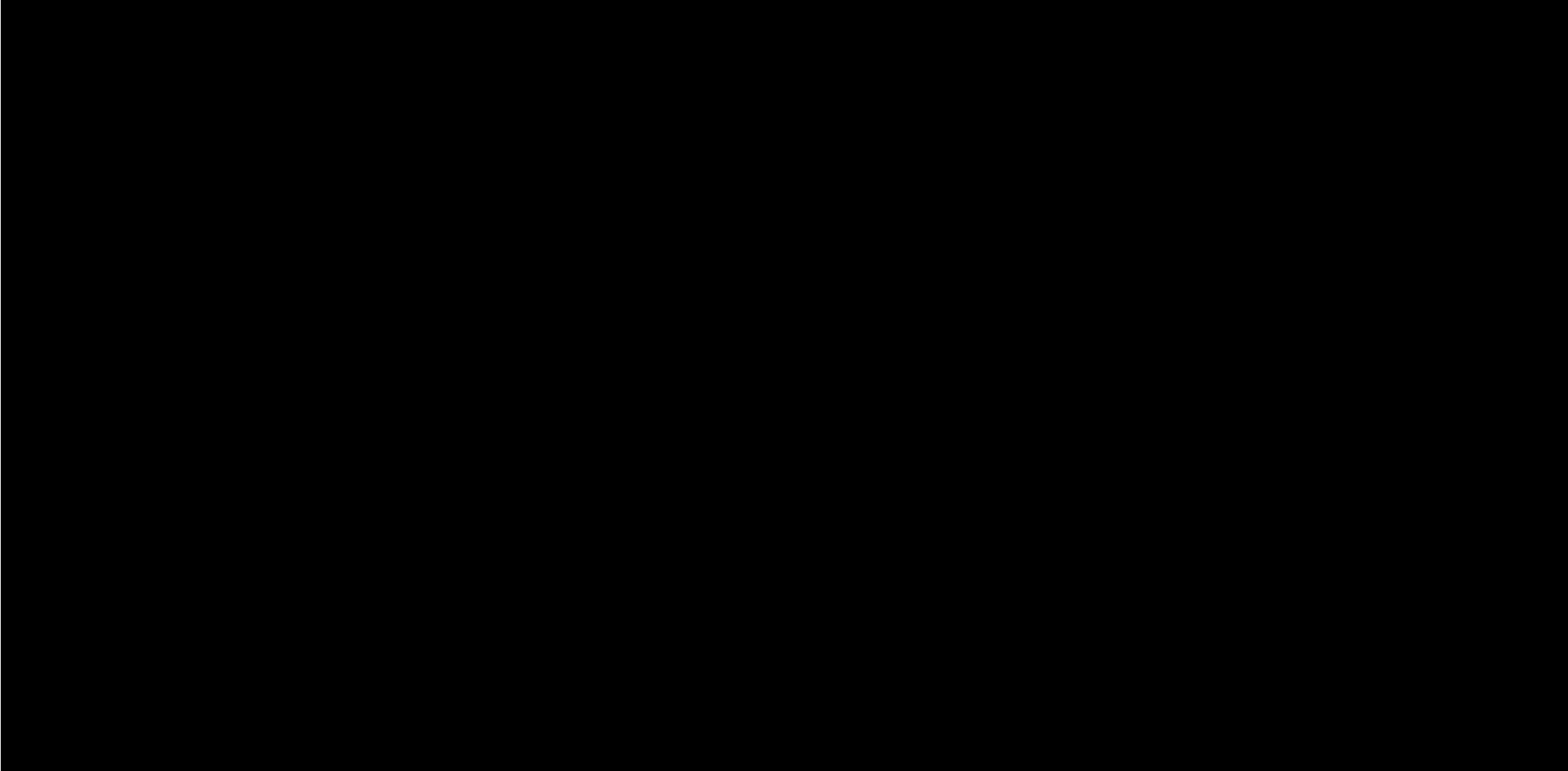
11. PROJECT TIMING

It is expected for the Rural Feeder Protection program to be completed by the end of 2030, with only 203 out of 310 affected 19kV feeders are to be resolved by 2025, to ensure the risks associated with the current network are managed appropriately. Refer to Appendix 4 for the breakdown of the timeline for the regulatory period 2020/21 to 2024/25.

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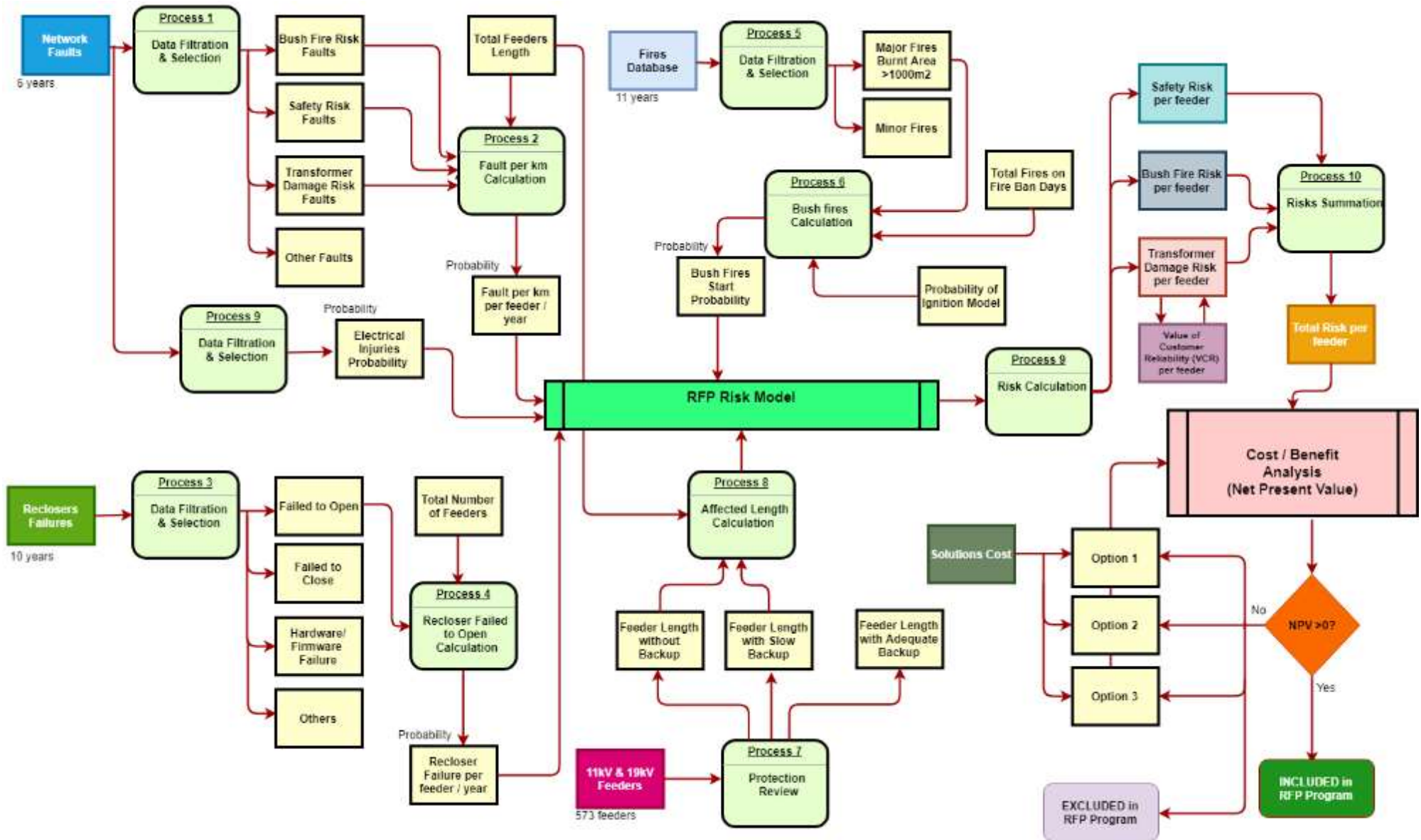
A. APPENDIX 1 – Reported Incidents of Inadequate Backup Protection

The incidents below occurred on feeders where primary protection devices have failed during faults [REDACTED]. Note that these are only the incidents that were reported.



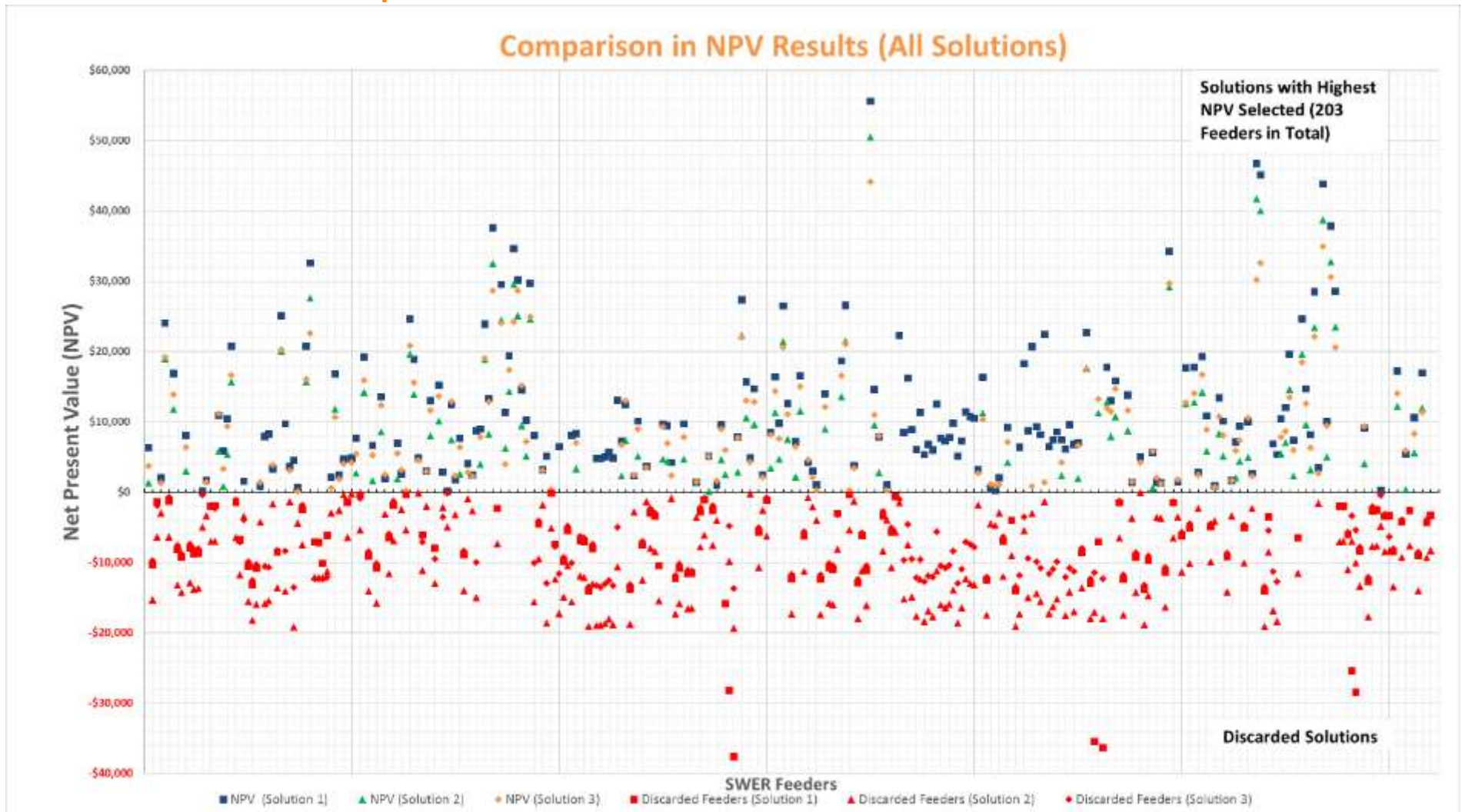
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B. APPENDIX 2 – Rural Feeder Protection Risk and Cost Benefit Analysis Models



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C. APPENDIX 3 – NPV Comparison of Solutions



The NPV value for solution 1, 2 and 3 represents a single feeder across the horizontal axis. All 310 inadequately protected feeders are considered for assesment with only 203 feeders producing positive NPV for at least one of the considered solutions.

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D. APPENDIX 4 – The RFP Program Cost and Timeline

Feeders Types	Solutions	Solutions Description	Unit Cost	Quantity	Total Cost
11kV	Solution 1	Substation 33kV Electronic Recloser and Sensitive Neutral Overcurrent Relay	\$ 360,000	-	Future Review
	Solution 2	Line 33kV Electronic Recloser and Sensitive Neutral Overcurrent Relay	\$ 250,000	-	Future Review
	Solution 3	Sectionalising Fuses and Settings Change	\$ 3,000	-	Future Review
19kV	Solution 1	19kV Recloser* with SCADA control plus existing Hydraulic Recloser	\$ 40,000	176	\$ 7,040,000
	Solution 2	19kV Recloser* without SCADA control plus existing Hydraulic Recloser	\$ 15,000	1	\$ 15,000
	Solution 3	Sectionalising Fuses and Settings Change	\$ 2,100	26	\$ 54,600
<i>*New low cost compact recloser</i>			Total	203	\$ 7,109,600

Table 5: Total Program Cost of RFP Program

Feeders	Years	Year 2020	Year 2021	Year 2022	Year 2023	Year 2024	Year 2025	Total
19kV Feeders 203 selected	Solution 1	18	35	35	35	35	18	175
	Solution 2	0	0	1	0	0	0	1
	Solution 3	3	5	5	5	5	3	26
Total Costs		\$ 726,300.00	\$1,410,500.00	\$1,425,500.00	\$1,410,500.00	\$1,410,500.00	\$ 726,300.00	\$7,109,600

Table 6: The Timeline of the Proposed RFP Program

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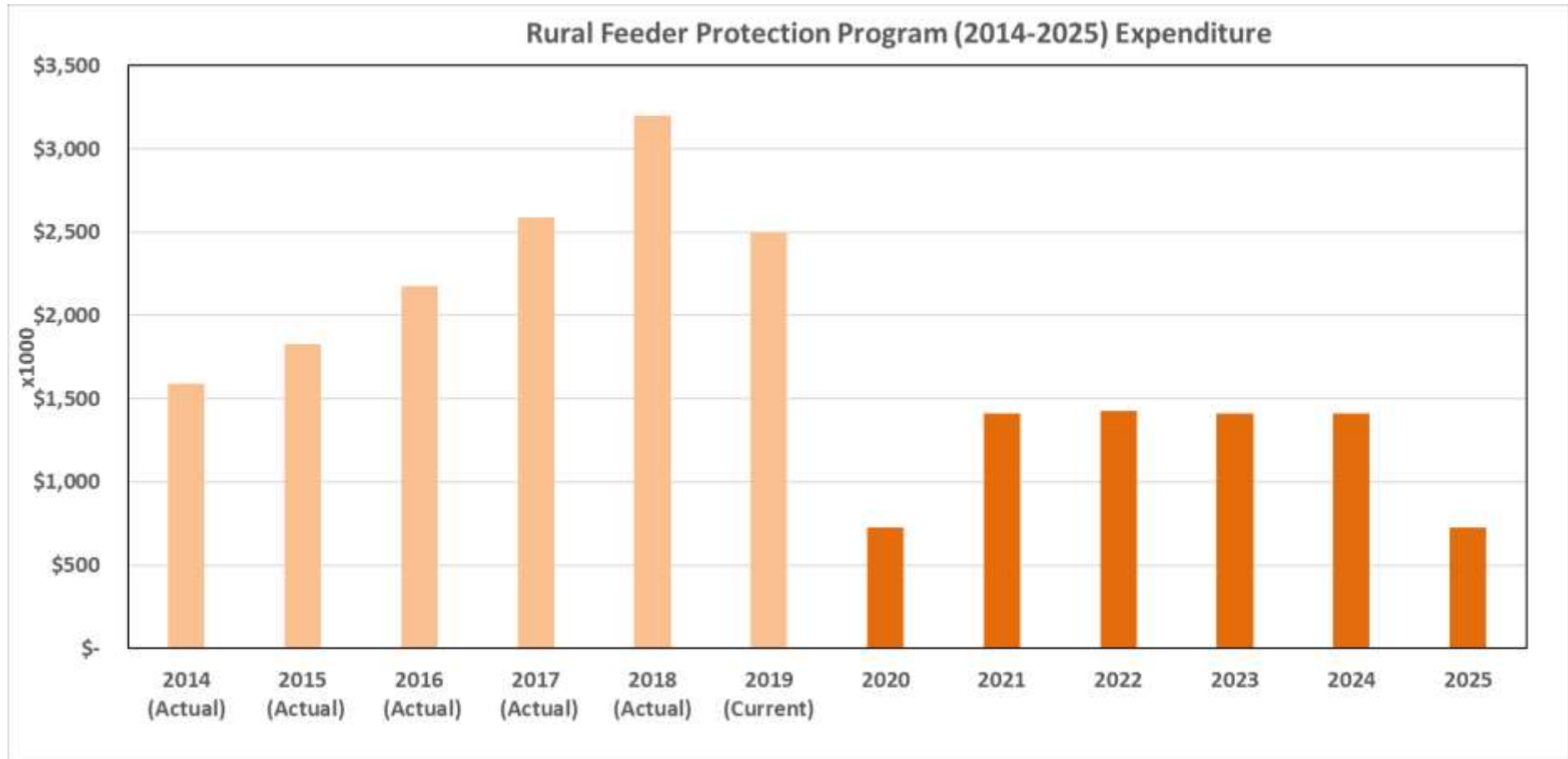


Figure 8: Yearly expenditure for Rural Feeder Protection program in RESET regulatory period 2020-2025

E. APPENDIX 5 – Reclosers Failure Analysis

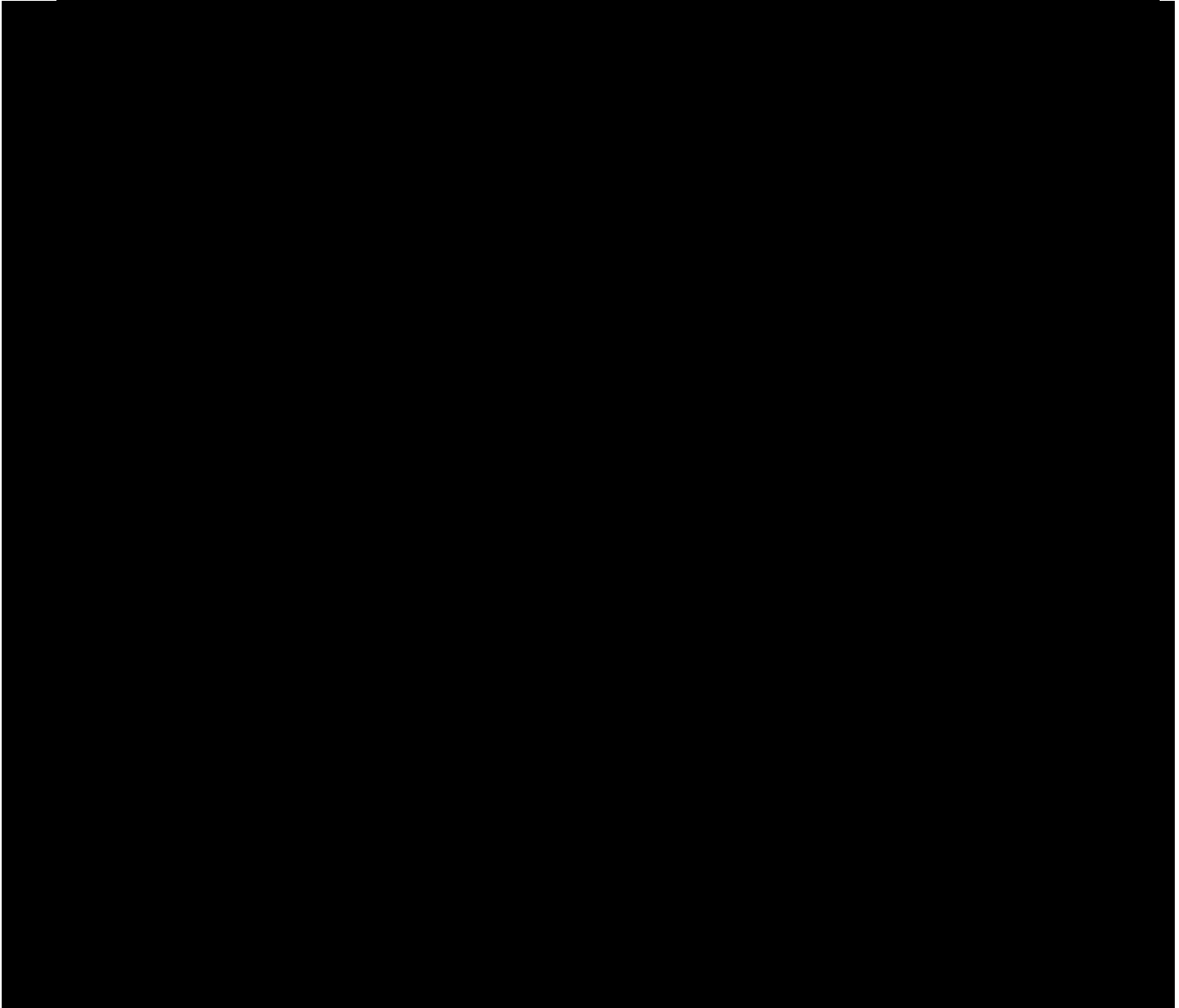


Table 7: Reclosers Failed to Open Failures Analysis

The table above shows the records of reclosers that failed to operate and the maximum possible number of days that the recloser may have failed and remained in a failed state. Note that these hydraulic reclosers are not SCADA monitored and there may be several in-service reclosers which were already in a failed state. The failures are not discovered until a fault event occurs or during recloser maintenance. It is entirely reasonable to expect that a recloser may fail (silent failure) during the last known operation or following a test on the last maintained date.

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F. APPENDIX 6 – Protection Reviews on 19kV Feeders

All the 19kV feeders within the network were reviewed to assess the protection coverage. Long feeders with a single protection recloser and smaller rated supply transformers protected by fuses tend to suffer more protection issues than any other feeders. Based on the review, three parameters are assigned to the reviewed feeders, i.e.:

1. Percentage of a feeder that has adequate backup protection (any credible faults that would be cleared by the backup protection device in less than 2 seconds)
2. Percentage of a feeder that has **slow backup** protection (any credible faults that would be cleared by the backup protection device between 2 to 10 seconds)
3. Percentage of a feeder that has **no backup** protection (any credible faults that would be cleared by the backup protection device after 10 seconds or would not be cleared until fault has further developed)

Based on the above criteria, the following results were gathered:

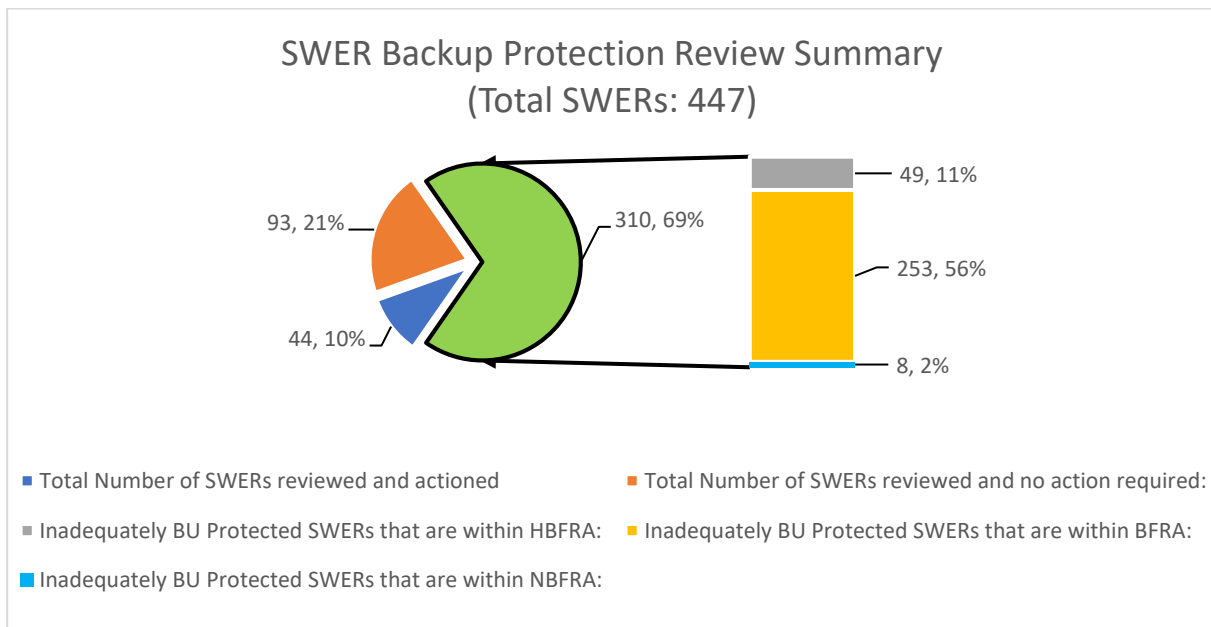


Figure 9: Protection Reviews of 19kV Feeders

The above chart depicts the status of the 447 SWER feeders currently on the network. Out of the 447 SWER feeders, 44 feeders have been reviewed and a protection solution has already been implemented,

[REDACTED]

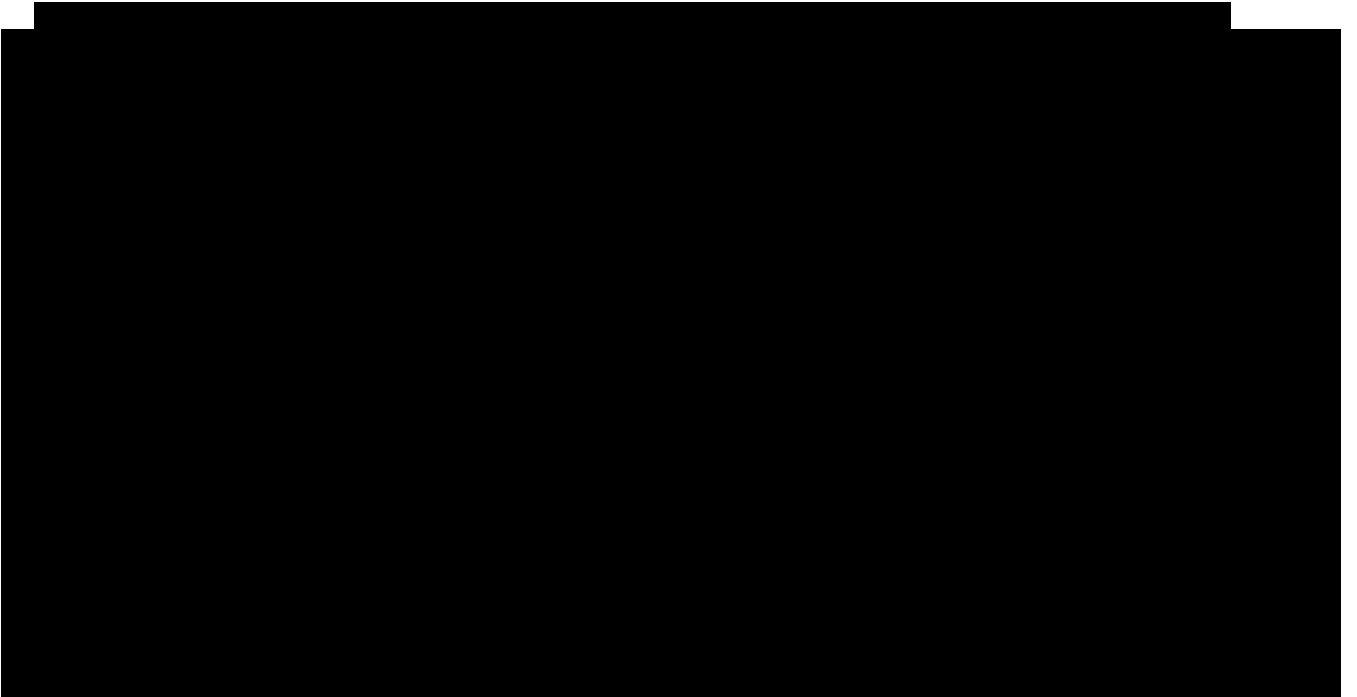
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The chart shows the number of feeders with different conductor length that suffer no/slow backup protection. [REDACTED]

[REDACTED]

[REDACTED]



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G. APPENDIX 7 – RFP Model Breakdown

The simplified risk model can be found in Figure 1 and detailed model can be found in Appendix 4.

G.1 Database

The SA Power Networks' own databases have been used to build the risk model. The input parameters for the RFP program model consist of following database:

1. Recloser failure data (6 years)
2. Network faults (10 years)
3. Fire Start incidents (11 years)
4. 11kV & 19kV Protection Reviews (573 feeders)

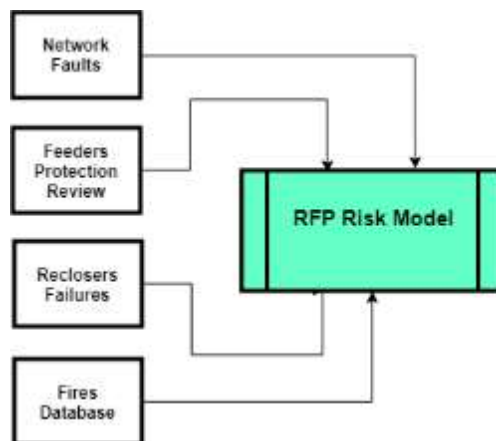


Figure 12: Database for Risk Model

G.2 Recloser Failures Data

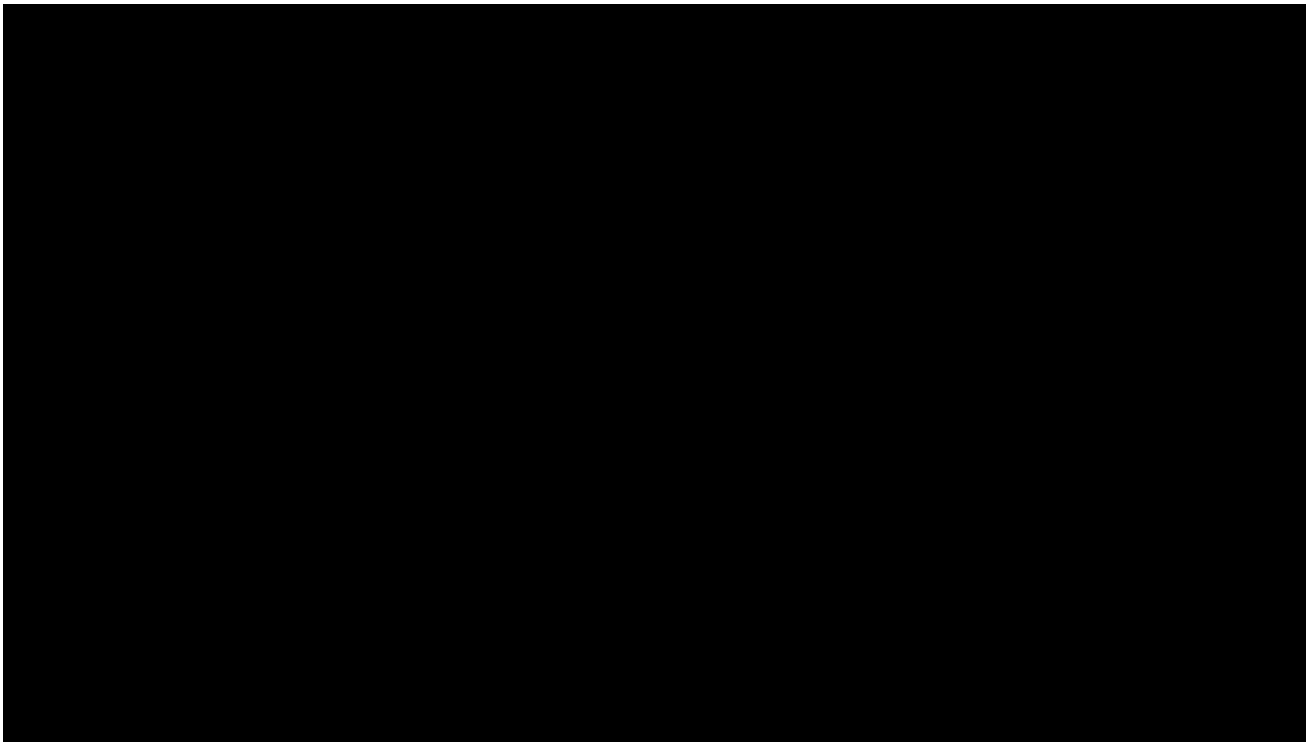
The failure modes that the RFP program focuses on are the reclosers that had failed to open during a fault or during scheduled maintenance. This type of failure mode is typically lower in the 11kV recloser population compared to the 19kV reclosers as the majority of 11kV reclosers (92%) installed on the network are electronic. The hydraulic reclosers used in the 19kV network are not SCADA monitored and often they can fail in “silent” until they are required to operate or discovered during the maintenance cycle.

All the 19kV hydraulic reclosers within the network have been replaced with a maintained unit by 2017 and all those reclosers are now in the next maintenance cycle. [REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]



G.3 Network Faults

21,204 HV interruption incidents with 46 different causes since the year 2010 have been analysed. Additional useful information associated with each fault such as weather conditions, cause of the fault, conductor downs, fire starts events, protection device operation, area burnt if fire started, third party contact are also recorded. From the additional information, filters have been applied and the possible risk per fault types are assigned, i.e.

1. Safety;
2. Bushfire;
3. Transformer damage.

Based on the HV interruption incidents, the average number of faults categorised into the respective risks are shown in the figure below, with the highest possible faults being the transformer damage related faults.

G.3.1 Safety-fault per feeder

From the total number of faults categorised as safety related risk, the faults are divided by the total length of the feeders to obtain a yearly safety related fault per km value. Each feeder will then have a safety-related fault per km value associated with its feeder length. The longer feeders are expected to experience higher chances of such faults occurring per year.

G.3.2 Bushfire-fault per feeder

The faults categorised as bushfire related risk are first grouped based on HBFRA or MBFRA regions. The faults are then divided by the total length of the feeders to obtain a yearly bushfire related fault per km value. Each feeder has a bushfire-fault per km value associated with its feeder length. Note that NBFRA feeders are excluded due to the substantially lower bushfire risk associated with feeders in these regions. However, these NBFRA feeders still suffer other safety and transformer damage risks resulting from inadequate backup protection. Also, only faults that occurred during Fire Ban Season (November to April) are considered in the model.

G.3.3 Transformer-damage-fault per feeder

From the total number of faults categorised as transformer damage related, the faults are divided by the total length of the feeders to obtain a yearly transformer damage related fault per km value. Each feeder will then have a transformer damage-related fault per km value associated with its feeder length.

G.4 Fire Start Incidents

The RFP model used SA Power Networks fires records starting from year 2008 and only considered fires that had caused a significant damage and burnt areas (more than 1000m²) during fire ban days (between Nov to Apr in the following year). The fires that started on fire ban days which caused a significant burnt area has potential to lead to bushfire starts. The figure below shows the average number of fires starts on rural feeders during fire ban days.

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$$\begin{aligned} \text{Safety Risk} &= \text{Death Risk} + \text{Injury Risk} \\ &= C(ECD) \times P(DBA) \times P(RFO) \times P(FBL) \\ &\quad + C(ECI) \times P(IBA) \times P(RFO) \times P(FBL) \end{aligned}$$

Where:

$C(ECD)$ = Consequence of Economic Cost per Death

$C(ECI)$ = Consequence of Economic Cost per Injuries

$P(RFO)$ = Probability Recloser Failed to Open

$P(DBA)$ = Probability of Death

$P(IBA)$ = Probability of Injuries

$P(FBL)$ = Probability of a Safety Fault Based on affected Length (sum of no and slow backup protection sections)

Note that the probability of fault occurring per feeder, $P(FBL)$ the fault is based on total affected length of the feeder, i.e. the sum of feeder length with slow and no backup protection as both conditions could lead to death or injury.

G.5.2 Bushfire Risk

The RFP model for assessing the bushfire risk component is closely compared to Bush Fire Risk Management's model to ensure consistency in approach and method. The RFP program aims to mitigate bush fire start by placing the backup protection devices into high speed single trip in addition to SA Power Networks' current practice for high bush fire risk days. Note that there is no additional benefit during non-bush fire risk days because any fire start is not expected to develop into bushfires on these days.

The bushfire risk reduction formula is as follows:

$$\text{Bushfire Risk} = C(EBF) \times P(RFO) \times P(FS) \times P(BFS) \times P(SR) \times P(FBT)$$

Where:

$C(EBF)$ = Consequence of Bushfire's Economic cost

$P(RFO)$ = Probability Recloser Failed to Open

$P(FS)$ = Probability of fire start

$P(BFS)$ = Probability of Bushfire Start

$P(SR)$ = Suppression Rate (90%)

$P(FBT)$ = Probability Fault Based on Total Length (100% of the length)

Note that the proposed new fast tripping backup protection device is able to reduce the probability of a bushfire start on any part of the feeder during high bush fire risk days, instead of on the affected section only. Hence the risk reduction in the calculation is based on the fault per whole feeder $P(FBT)$.

G.5.3 Probability of Ignition

It shows the probability of ignition under different environmental conditions (windspeed, air temperature, fuel moisture content) for different current magnitudes. For a

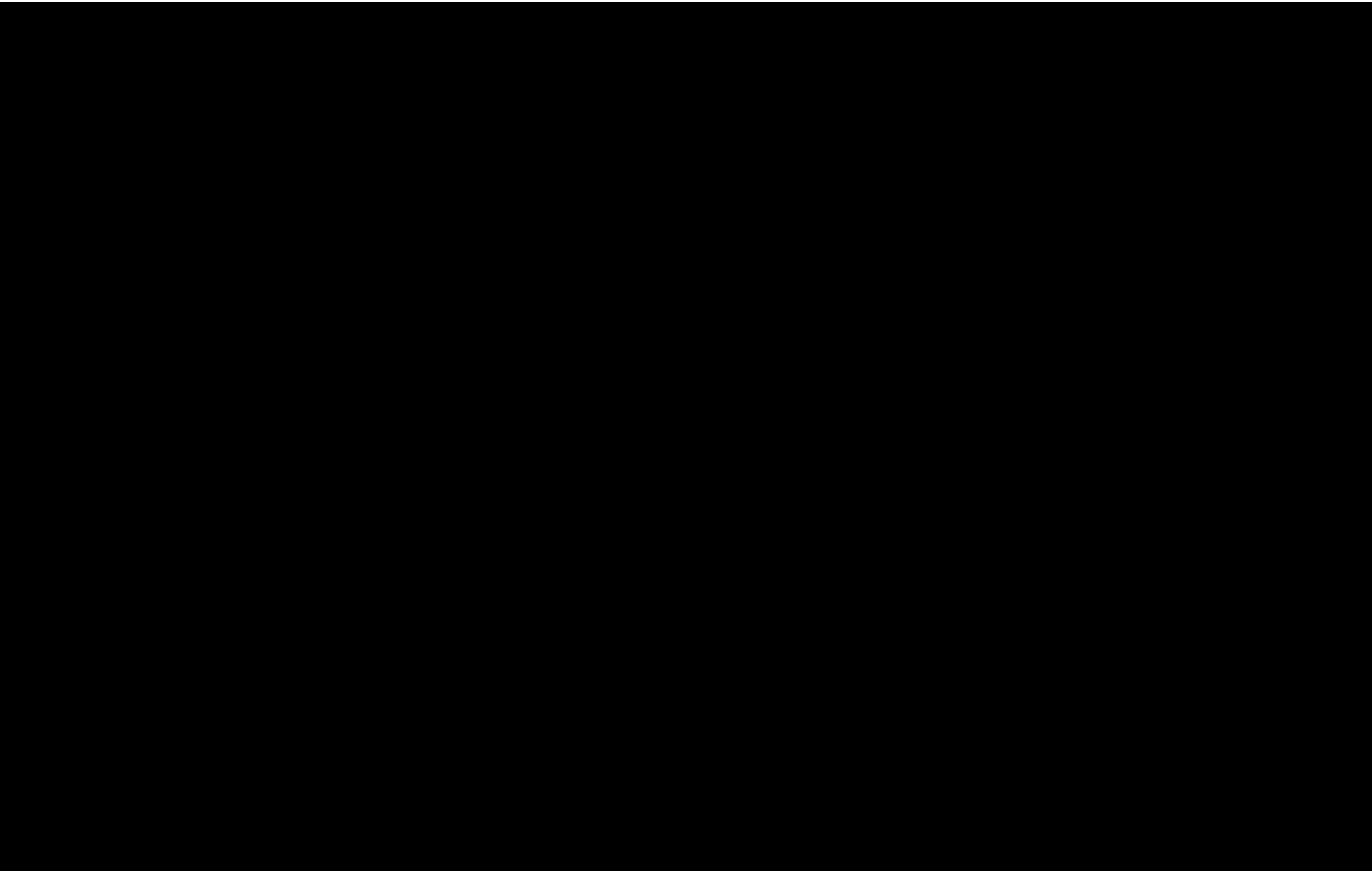
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typical SWER fault current between 50A to 160A, it shows that [REDACTED]

[REDACTED]

[REDACTED]

[REDACTED]



To ensure that RFP's model does not overstate bushfire risk, the bushfire start probability is compared against the probability of Bushfire Management model from the Bushfire Management Group. The graph below depicts the validity check of the two models, with the inclusion of primary protection failures probability in both models. The two models are closely aligned.

G.5.4 Transformer Damage Risk

Transformer Damage risk is divided into Major and Minor damage risk when the primary protection fails. It is assumed the certainty of a transformer to suffer (major or minor) damage when a primary protection without adequate backup protection, has failed to operate for a permanent fault. There is subsequent risk followed by the initial transformer damage incident, i.e. economic cost due to the supply interruptions. Many rural feeders have limited feeder transferability and therefore supply may only be restored when the supply transformer is repaired or replaced. To estimate the economic cost due to the transformer damage, the Value of Customer Reliability (VCR) has been applied.

The transformer damage risk formula is as follows:

Transformer Damage Risk

$$\begin{aligned} &= \text{Major Transformer Damage Risk} + \text{Minor Transformer Damage Risk} \\ &= C(TDM + VCRM) \times P(RFO) \times P(FNL) + C(TD + VCR) \times P(RFO) \times P(FSL) \end{aligned}$$

Note that Major Risk includes Subsequent Risk associated with major transformer damage whereas Minor Risk includes Subsequent Risk associated with minor transformer damage. It is considered a major transformer damage if the transformer has failed catastrophically due to an undetected fault and it is considered a minor transformer damage if the damage caused to the transformer due to slow backup protection is repairable on site.

Where:

$C(TDM)$ = Consequence of Transformer Damage Major

$C(TD)$ = Consequence of Transformer Damage minor

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$C(VCRM)$ = Consequence of VCR Impact due to Major TF damage (Based on 12-hour outage)

$C(VCR)$ = Consequence of VCR Impact due to minor TF damage (Based on 4-hour outage)

$P(RFO)$ = Probability Recloser Failed to Open

$P(FNL)$ = Probability Fault on No backup based on km Length

$P(FSL)$ = Probability Fault on Slow backup based on km Length

G.5.5 Transformer Damage vs Clearing Times

Majority of the SWER isolation transformers on the 19kV network are 150kVA rated with a typical load current of about 8A. The fault currents typically range from 160A at the secondary side of the isolation transformer, to 50A at the end of line. For any faults on the 19kV feeder that are not cleared in a timely fashion, significant stress to the isolation transformer can occur. The extent of damage from such fault is a function of the current magnitude, fault duration, and total number of fault occurrences. The fault duration is controlled by the ability of the hydraulic recloser to operate and isolate the faulted section. Based on the transformer protection curve published by IEEE (Category 1 IEEE C37.91), The maximum fault clearing time a transformer can withstand before experiencing an internal failure is given as:

$$t = \frac{1250}{I^2}$$

Where:

I = Symmetrical fault current in times normal base current

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G.6 Net Present Value

From the calculated risks in terms of dollars per year, different solution costs are used in the NPV calculation to work out which solution is capable of providing greater economic benefits throughout the protection asset life. The asset life span of 25 years has been used in the NPV formula for solutions with electronic devices. The associated on-going maintenance cost and the additional benefits attached to different solutions are also part of the NPV calculation. Note that the whole RFP program is scrutinised down to an individual feeder level and feeders will be excluded if the risks could not be supported by the economic benefits.

The Net Present Value formula is as follow:

$$NPV = \sum_{t=1}^N \frac{R_t}{(1+r)^t}$$

Where:

R_t = net cash inflow-outflows expected during a particular year

r = corporate discount rate = 2.63%

N = number of time periods

t = the time of the cash flow

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H. APPENDIX 8– Regulatory Drivers

There are a number of safety related legislative or regulatory obligations imposed on SA Power Networks that relate specifically to managing safety risks in our network. The extracts from the National Electricity Objective (NEO) and National Electricity Rules (NER) published documents as follows:

National Electricity Objective

The National Electricity Objective (NEO), set out in the National Electricity Law (NEL), is to:

"promote efficient investment in, and efficient operation and use of, electricity services for the long-term interests of consumers of electricity with respect to -

- i. price, quality, **safety**, reliability and security of supply of electricity; and*
- ii. the reliability, **safety** and security of the national electricity system".*

National Electricity Rules (Schedule 5.1)

The National Electricity Rules in Chapter 5, Schedule S5.1.9 (c) and (f) Protection systems and fault clearance times requires that Network Users:

- i. Subject to clauses S5.1.9(k) and S5.1.9(l), a Network Service Provider must provide **sufficient primary** protection systems and **back-up** protection systems (including breaker fail protection systems) to ensure that a fault of any fault type anywhere on its transmission system or distribution system is automatically disconnected in accordance with clause S5.1.9(e) or clause S5.1.9(f).
- ii. The fault clearance time of each breaker fail protection system or similar back-up protection system of a Network Service Provider must be such that a short circuit fault of any fault type that is cleared in that time **would not damage any part of the power system** (other than the faulted element) while the fault current is flowing or being interrupted

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I. APPENDIX 9 – NPV Calculation and Options Assessment

See confidential model, supporting document 5.19.1 - Rural Feeder Protection model