
# DISTRIBUTION FEEDER SAFETY IMPROVEMENT

## Project PS012 2018/19 – 2019/20

## Prepared by Asset and Network Planning

July 2017

Endeavour Energy

REVIEW AND APPROVAL SCHEDULE

| Responsibility | Position | Name | Signature | Date |
|---|---|---|---|---|
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# 1.0 EXECUTIVE SUMMARY

This business case seeks approval for the funding for the final stage of the PS012 program to improve the safety performance of protection systems for distribution feeders in Endeavour Energy's zone substations from 2018/19 – 2019/20. This business case has been initiated by a statement of asset need from Manager Asset Standards and Design.

The protection systems in many of Endeavour Energy's older zone substations utilise aged electromechanical technology which is slow to clear faults on the network compared to modern numerical relays. Adding a high speed numerical relay with hi-set overcurrent characteristics to each zone substation 11kV feeder protection system will provide the benefits of:

- Reduction in the severity of arc-flash incident injuries;
- Reduction in the severity of electric shock incidents to the public and workers;
- Reduction of bushfire ignition risk,
- Reduction in through-fault energy and cumulative damage to network assets;
- Reduction in step and touch potential hazard to the public and workers;
- Enhanced protection system reliability and compliance.

This business case seeks approval for works on 159 feeder protection systems at 19 zone substations during the 2018/19 – 2019/20 period as the final stage of the program.

The total cost of the works in this stage of the program is $5.80 million in real terms and $6.00 million in nominal terms. A further risk based contingency of $0.6 million, being 10% of the project cost estimate is also proposed. Therefore, the total project cost, for which approval is sought, including contingency is estimated to be $6.60 million.

The Portfolio Investment Plan (v8.3) includes a provision of $8.82 million for program PS012 during 2018/19 – 2019/20. Of this funding, $3.60 million in 2018/19 is allocated for the works covered in the 2017/18 PS012 business case.

In June 2017, a review of network needs was carried out and a commercial view has been applied to work volumes identified in replacement capital investment. This review resulted in additional investment being required to manage network risk levels. Therefore a change control will be required to increase the funding for PS012 in order to complete the final stage of the works.

Accordingly, it is recommended that:

- A capital expenditure of $6.00 million for the works on 11kV protection systems at 19 zone substations during 2018/19 – 2019/20, as detailed in this business case, be approved;
- A contingency sum of $0.60 million, representing approximately 10% of the estimated cost of the project to cover unforseen events be approved;

The total project estimate, including the contingency sum, totals $6.60 million

# 2.0 INTRODUCTION

## 2.1 PURPOSE

This business case seeks approval for the expenditure for the final stage of the PS012 program to improve the safety performance of 11kV distribution feeder protection systems in zone substations throughout Endeavour Energy's network during 2018/19 and 2019/20. This business case is to address the completion of the PS012 program endorsed in the initial business case in 2015 [1] and subsequent business case in 2017 [2].

This business case has been initiated by a statement of asset need (SAN) from Manager Asset Standards and Design which reassessed the risks posed by the existing aged feeder protection systems and re-affirmed the need to continue the PS012 program to completion. Refer Appendix A for details of the SAN.

## 2.2 BACKGROUND

### 2.2.1 PROTECTION SYSTEMS

The function of distribution feeder protection systems is to monitor secondary current from current transformers and operate to trip a circuit breaker when the properties of the current indicate that a fault has occurred in the network. It is important that this process occurs as quickly as possible to reduce the exposure of the network to fault current duration and risk to the public as well as electricity workers.

Within Endeavour Energy's zone substations there are currently 2,883 distribution protection systems protecting the Company's 11kV and 22kV distribution feeders. Of these some 690 are the older electromechanical or electronic designs and 2,133 the newer microprocessor based numerical systems.

### 2.2.2 PS012 PROGRAM STATUS

Program PS012 focusses on the electromechanical/electronic distribution feeder protection systems and earlier numerical relay models that do not have the required speed and performance of the modern relays and are not approved for replacement under other projects. There were 537 such relays at the start of the PS012 program. The first stage, during 2015/16 – 2016/17, included the installation of numerical relays on 212 feeders in 24 zone substations. This represents approximately 39% of the network need. The second business case approved in May 2017 addressed the next 166 relays in 16 zone substations to be completed during 2017/18 – 2018/19. This represents approximately 31% of the network need.

159 feeders at 19 zone substations remain to be completed. This business case includes the installation of numerical relays on the remaining feeders to complete the PS012 program.

# 3.0 RENEWAL NEED

The protection systems in many of Endeavour Energy's older zone substations utilise aged electromechanical relay technology which is slow to clear faults on the network compared to modern numerical relays. Adding a high speed numerical relay with hi-set overcurrent characteristics to each zone substation 11kV feeder protection system which is currently protected by electromechanical relays will provide the benefits of:

- A material reduction in the impact of uncontrolled discharge of electricity accidents, particularly arc flash accidents;
- An increase in the likelihood of high impedance faults, such as lines on the ground and tree contact, being detected and a reduction in the likelihood of bushfire ignition on total fire ban days;

- A lower risk of non-operation of feeder protection and minimisation of the subsequent reliability impact due to duplication and the addition of circuit breaker failure systems.

The 2015/16 PS012 business case [1] detailed five arc flash incidents. These are the incidents 1 to 5 in Table 1 which shows the estimated reduction in the degree of burns to the victim had high speed protection been available at the time. After that business case was written there have been two incidents in Endeavour Energy's network which are incidents six and seven in the table. High speed protection was available in both of these scenarios and as the injury to the victims was limited to first degree burns only. The table shows that if high speed protection had not been available the victims would have suffered second degree burns. This shows the improvements in safety to the network that this program is providing.

TABLE 1 – ARC FLASH INCIDENTS

| Ref | Fault level (kA) | Clearance time (s) | Energy cal/cm$^2$ @ 46cm | Days victim in ICU | %TBSA (Total burn surface area) | Full thick-ness burns (%TBSA) | Mid dermal burns (%TBSA) | New settings installed? | Energy (would have been if new safety improvements were implemented) cal/cm$^2$ @ 46cm | Energy (would have been if improvements weren't yet implemented) cal/cm$^2$ @ 46cm | Energy % (new as a proportion of old) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 7.8 | 2.3 | 42.2 | 13 | 30% | 20% | 10% | | 7.3 | - | 17% |
| 2 | 5.2 | 0.6 | 14.4 | 8 | 40% | 35% | 5% | | 2.0 | - | 14% |
| 3 | 11.7 | 0.43 | 12.2 | 3 | 13% | 0% | 13% | | 4.7 | - | 39% |
| 4 | 5.8 | 0.4 | 5.3 | 3 | 15% | 8% | 7% | | 2.2 | - | 42% |
| 5 | 1.2 | 1.2 | 2.9 | 0 | 5% | 0% | 5% | | 2.7 | - | 93% |
| 6 | 5.0 | 0.16 | 1.9 | 0 | 0% | 0% | 0% | Yes | - | 5.3 | 36% |
| 7 | 3.4 | 0.13 | 0.6 | 0 | 0% | 0% | 0% | Yes | - | 3.7 | 16% |

Notes:
Onset of 2nd degree burns is 1.2 cal/cm$^2$
Old PPE is considered safe for at least 2 cal/cm$^2$
New PPE is rated at 4 cal/cm$^2$
Onset of 3rd degree burns is 8 cal/cm$^2$

## 3.1 RISK ASSESSMENT

Table 5 is based on the Company's risk assessment procedure, Board Policy 2.0.5 [2] and assesses the principal risks presented by the protection assets noted. In this instance, all protection systems under consideration exhibit generally the same safety and condition issues and therefore the same risk assessment is applicable to each. Note that this risk assessment is the same as that included in the approved 2015 business case which initiated program PS012.

TABLE 5 – RISK ASSESSMENT

| Event | Likeli-hood | Impact | Risk rating | Consequence and Comments | Proposed Treatment | Expected Risk after Treatment |
|---|---|---|---|---|---|---|
| Arc-flash incident | Likely (B) | Severe (5) | **Extreme (B5)** | Arc-flash incidents to staff and the public occur about once a year. | Installing numerical relays with reduced clearance times will reduce the severity of arc-flash hazards. | High (B3)[1] |

[1] This risk remains high, especially to workers carrying out switching. However, this risk is mitigated further through safety procedures and PPE.

| Event | Likeli-hood | Impact | Risk rating | Consequence and Comments | Proposed Treatment | Expected Risk after Treatment |
|---|---|---|---|---|---|---|
| Electric shock due to indirect contact with the network | Possible (C) | Severe (5) | **High (C5)** | Electric shock incidents to workers and the public occur once every seven years on average. | Installing numerical relays with reduced clearance times will reduce the severity of electric shock hazards. | Medium (C3) |
| Fatality due to uncleared mains on the ground | Unlikely (D) | Severe (5) | **High (D5)** | Risk of bushfire initiating | Install core balance CTs on 11kV feeders | Medium (E5) |

This business case is a continuation of the existing endorsed PS012 program. Refer to the SAN attached as Appendix A and to the 2015/16 PS012 business case [1] for further details of the risk-cost assessment which justifies this program.

# 4.0 PROJECT DETAILS

## 4.1 GENERAL

The next stage of the program includes work on 159 x 11kV feeders at 19 substations. It is proposed that these works be completed in the 2018/19 – 2019/20 period.

## 4.2 SITE PRIORITISATION AND PHASING

Table 2 below shows the remaining 19 substations in priority order as determined by their cost benefit ratio as assessed in the SAN.

The number of required core balance CTs shown in the table is an estimate only and will be refined during the design phase of the program to investigate whether each feeder in the program enters a bushfire prone area and therefore, whether core balance CTs are required.

The 19 substations included in this business case are shown to be completed in the 2018/19 – 2019/20 period. The table also shows the proposed phasing of the work over the two year period of the program.

The exact timing for each protection system upgrade is not critical and the program may be adjusted to suit logistical requirements providing the works are completed within the specified timeframe and nominally in the priority order shown.

TABLE 2 – SITE PRIORITISATION AND PHASING

| Zone substation | Quantity of feeders | Number of feeders per year | | Install core balance CTs |
|---|---|---|---|---|
| | | 18/19 | 19/20 | |
| Portland | 2.7 | 3 | | |
| Inner harbour | 1.7 | 10 | | |
| Kenny Street | 1.7 | 8 | | |
| Moorebank | 1.5 | 12 | | |
| Berrima Junction | 1.4 | 1 | | |
| Seven Hills | 1.4 | 14 | | |
| Lennox | 1.4 | 13 | | |
| Horsley Park | 1.4 | 9 | | |
| Blackmans Flat | 1.4 | 5 | | |
| Port Central | 1.3 | 6 | | |
| Appin | 1.2 | 4 | | 4 |
| Cabramatta | 1.2 | 11 | | |

| Zone substation | Quantity of feeders | Number of feeders per year | | Install core balance CTs |
|---|---|---|---|---|
| | | 18/19 | 19/20 | |
| Prospect | 1.1 | 11 | | |
| Sherwood | 1.1 | | 12 | |
| Woodpark | 1.1 | | 9 | |
| North Rocks | 1.0 | | 9 | |
| Luddenham | 1.0 | | 4 | 4 |
| Greystanes | 0.5 | | 12 | |
| Glossodia | 0.4 | | 6 | 6 |
| Total | | **107** | **52** | **14** |

## 4.3 PROJECT SCOPE OF WORKS

The scope of works at each site includes;

- Removal of the existing feeder overcurrent and earthfault relays and replacement with duplicate numerical relays;
- Installation of core balance CTs on the 11kV feeders in bushfire prone areas as indicated in Table 2;
- Implementation of a circuit breaker fail scheme and adjustment of the transformer over-current settings;
- Commissioning of the new relays and protection systems;
- Installation of an Ethernet LAN between new relays and the SCADA;
- Implementation of advanced fault information to SCADA and remote retrieval of data from the protection relays to the local RTU and SCADA master station where possible;
- Disposal of redundant equipment.

## 4.4 CAPACITOR OR AUXILIARY ONLY CONNECTIONS

In the substations nominated for feeder protection modernisation it is noted that there are relays that provide protection for a feed to a capacitor or an auxiliary busbar only. As these arrangements do not supply the 11kV distribution network they do not require improved protection and therefore are not included in the scope of this program.

However, if the arrangement involves a capacitor or auxiliary connection that is doubled up to an 11kV feeder, this is included in the scope of this program.

## 4.5 PROJECT ESTIMATE

Estimated costs for each of the sites for this program are shown in Table 3. The phasing of the program is also shown in the table. All costs are in real 2017/18 terms. Further details of these cost estimates are shown in Appendix B.

TABLE 3 – SITE COST ESTIMATES AND PHASING

| Zone substation | Quantity of feeders | Core balance CTs | Cost estimate ($) | |
|---|---|---|---|---|
| | | | 18/19 | 19/20 |
| Portland | 3 | | 143,600 | |
| Inner harbour | 10 | | 314,850 | |
| Kenny Street | 8 | | 275,350 | |
| Moorebank | 12 | | 460,950 | |
| Berrima Junction | 1 | | 89,800 | |
| Seven Hills | 14 | | 425,750 | |

| Zone substation | Quantity of feeders | Core balance CTs | Cost estimate ($) | |
|---|---|---|---|---|
| | | | 18/19 | 19/20 |
| Lennox | 13 | | 402,600 | |
| Horsley Park | 9 | | 321,500 | |
| Blackmans Flat | 5 | | 191,400 | |
| Port Central | 6 | | 234,550 | |
| Appin | 4 | | 170,450 | |
| Cabramatta | 11 | | 390,800 | |
| Prospect | 11 | | 396,300 | |
| Sherwood | 12 | 4 | | 421,950 |
| Woodpark | 9 | 4 | | 316,500 |
| North Rocks | 9 | | | 324,000 |
| Luddenham | 4 | 6 | | 252,450 |
| Greystanes | 12 | | | 385,950 |
| Glossodia | 6 | | | 279,510 |
| **Total** | **159** | **14** | **3,820,000** | **1,980,000** |
| | | | **Total project (nearest $10,000)** | **5,800,000** |

## 4.6 CONTINGENCY

A contingency amount of $600,000 (representing 10% of the estimated project cost) is proposed to allow for unforeseen cost increases due to the works being conducted in aged protection panels and substations with asbestos. Some sites also contain protection relays in a separate control rooms remote from the switchgear which adds to complexity and cost of the wiring.

Other sites that require the installation of core balance CTs require works preparing straight-through joints in the 11kV cables and/or the installation of air cable boxes may experience delays due to working inside an aged substation cable basement with space and layout constraints.

These risks are reflected in Table 4 against the various functional activities or work packets required to implement the project.

TABLE 4 – CONTINGENCY PROVISIONS

| | Contingency provisions | |
|---|---|---|
| Item | Amount ($ Real) | Explanation |
| Work in aged sites | 350,000 | Unforeseen site conditions, program duration increase. Additional panels including labour |
| Sites with remote P&C panels | 80,000 | Additional complex wiring requirements |
| Presence of asbestos | 150,000 | Restrictive procedures and/or additional costs for removal of the asbestos |
| Work on 11kV cable joints and cable boxes | 20,000 | Unforeseen site conditions, additional commissioning tests due to aged cables, program duration increase |
| **Total (nearest $10,000)** | **600,000** | |

## 4.7 PROJECT FUNDING

This project falls within SARP program PS012 – Distribution feeder protection modernisation. The program summary in the Portfolio Investment Plan (PIP) v8.3 is shown in Table 5 and reflects the risk level and priority of the program.

TABLE 5 – PIP SUMMARY

| PIP element | PIP rating |
|---|---|
| Project ID | PS012 |
| Principal driver | Renewal |
| Weighted ranking | 4,650 |

The Portfolio Investment Plan (v8.3) includes a provision of $8.82 million for program PS012 during 2018/19 – 2019/20. This funding is sufficient for the works proposed in this business case. Of this funding, $3.60 million in 2018/19 is allocated for the works covered in the 2017/18 PS012 business case [2].

In June 2017, a review of network needs was carried out and a commercial view has been applied to work volumes identified in replacement capital investment. This review resulted in additional investment being required to manage network risk levels. Therefore a change control will be required to increase the funding for PS012 in order to complete the final stage of the works.

The expenditure is proposed to commence in the 2018/19 and be completed in 2019/20. The proposed expenditure each year, including contingency and the allocations currently made for this program in the PIP is shown in Table 6.

TABLE 6 – PROJECT EXPENDITURE SPREAD

| Estimated cost ($ M) | 2018/19 | 2019/20 | Total |
|---|---|---|---|
| PIP 8.3 provision (PS012) (nominal) | 4.36 | 4.47 | **8.82** |
| Estimated project PS012 (real 2017/18) | 3.82 | 1.98 | **5.80** |
| Estimated project PS012 cost (nominal) | 3.92 | 2.08 | **6.00** |
| Contingency | | | **0.60** |
| **Total project** | | | **6.60** |

# 5.0 RECOMMENDATIONS

It is recommended that:

- A capital expenditure of $6.00 million to improve distribution feeder protection systems at 19 zone substations to complete the PS012 program over the period of 2018/19 – 2019/20 as detailed in this business case be approved;
- A contingency sum of $0.60 million, representing 10% of the project estimated cost to cover unforseen events be approved;

The complete project estimate including the base costs and the contingency sum totals $6.60 million.

# 6.0 APPENDICES

**APPENDIX A** - Statement of Asset Need

**APPENDIX B** - Cost estimate

# 7.0 REFERENCES

[1] Asset & Network Planning, “PS012 - Distribution Feeder Safety Improvement - Business Case 2015-16 (1.6),” 2015.

[2] Asset Strategy & Planning, PS012 - Distribution Feeder Safety Improvement - Business Case 2017-18 (r1.5), 2017.

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## APPENDIX A - STATEMENT OF ASSET NEED

Refer to the attached Appendix A – Statement of Asset Need – Distribution Feeder Protection Modernisation, March 2017

STATEMENT OF ASSET NEED

# DISTRIBUTION FEEDER PROTECTION MODERNISATION

## SARP PS012

March 2017

Endeavour Energy

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## 1.0 EXECUTIVE SUMMARY

This statement of asset need (SAN) has been written to see the continuation of SARP program PS012: Distribution Feeder Safety Improvement and Fire Mitigation. This SAN is a continuation of previously approved SAN attached at Appendix F. The program will see the continued replacement of old technology protection relays installed on distribution feeders with modern microprocessor protection relays. This modern technology will result in substantial benefits to safety, some reduction in expenditure, and several other benefits.

Since the initiation of PS012 there have been a number of changes to the scope and implementation strategy. This statement of asset need carries forth all recommendations of the previous SAN (Appendix F) with modifications to scope and implementation as a result of revised costings and learnings from the first two years of PS012. The purpose of this document is to highlight these changes to scope and costings.

The total cost of the forthcoming program has been re-estimated to be $10.6 million (plus $0.9 million contingency) over 4 years commencing in 2017/18 and the program will cover 303 feeders across 31 zone substation sites. **This statement of asset need recommends that a business case be developed to gain approval for $11.5 million total for the 2017/18 through 2020/21 financial years for the implementation of these works.**

**<u>Program benefits</u>**

The key benefits of the program stem from a substantial reduction in high voltage electrical fault clearance times, an increase in the sensitivity of earth fault protection at sites with the highest contribution of network bushfire risk sites, from the provision of redundancy through duplication of protection systems, and from the inclusion of circuit breaker failure systems.

The key benefits of PS012 include:

- **A material reduction in the impact of uncontrolled discharge of electricity accidents, particularly arc flash accidents.** This control will reduce the arc flash energy by a factor of around 3 at high fault levels on most distribution feeders, substantially reducing the severity of injurious arc flash accidents which at present happen at a rate of 1-2 occurrences per annum and involve both employees, contractors, ASP's and members of the public.

- **An increase in the likelihood of high impedance faults, such as lines on the ground and tree contact, being detected and a reduction in the likelihood of bushfire ignition on total fire ban days.** Where core balance CTs are installed (sites at Appendix B) the sensitivity to high impedance faults will increase by a factor of 4 with the detection level reduced from 4A to 1A.

- **A lower risk of non-operation of feeder protection and minimisation of the subsequent reliability impact** due to duplication and the addition of circuit breaker failure systems. This has been assessed to be necessary to align to industry practice, Endeavour Energy Standards, and in order to reduce feeder fault risk to be ALARP.

The program will also see numerous secondary benefits including:

- A substantial reduction in the gross risk and reduction in costs associated with achieving earthing system compliance.
- A substantial reduction in the cost associated with the replacement of fault rating exceeded conductors.
- A reduction in through fault energy, reducing the cumulative damage to equipment such as conductors and transformers, leading to longer equipment lives and better reliability.
- Remote indication of fault type and fault current. This can assist in the assessment of risk and the locating of permanent faults on the network, thus potentially reducing outage times.
- Provide detailed fault records, assisting with the investigation of incidents and helping to permit a better understanding of events which can lead to appropriate choice of remedial actions and can help enhance safety and reliability in the future.
- An improvement in power quality (reduced dip times). This has the potential to reduce impacts on and reduce complaints from sensitive customers.

## 2.0 KEY CHANGES

In continuation of the previous statement of asset need, there are a number of key changes proposed for the forthcoming program of PS012. These changes include:

- **Strategic change to the application of core balance current transformers**. The installation of core balance CTs has been a learning experience for Endeavour Energy, being the first utility in Australia to try the application. The reliability impact of such a measure was highly uncertain and has unfortunately been greater than that which would be desirable. A revised assessment of the costs and benefits of core balance CT indicates that the installation is no longer justified at the majority of sites, and is only justified at high bushfire risk sites where the application of a lower setting can be implemented on total fire ban days only.

- **Total protection panel replacement including two new protection relays at all sites.** The previously recommended option (single additional relay) is no longer considered to provide the greatest cost functionality benefit. The cost of total panel replacement has been demonstrated at a number of sites to be much more economical than first anticipated and is the preferred option at all sites.

- **Reprioritisation of sites based on revised risk levels and revised parameters used in the risk cost benefit calculation.** A revised value for the Value of Statistical Life (VSL) has been applied following the approval of Company Procedure GNV1119. The site specific bushfire risk estimates have been updated on a per site basis as a result of recent studies and literature review. The value of safety risk associated with arc flash accidents has been updated based on real medical information associated with incidents which have occurred over the last 5 years. The value of total economic cost of bushfire relating to Endeavour Energy's network assets has revised following a separate review (Appendix E). The value of the 'safety uprating factor' has been modified to reflect latest advice.

# 3.0 IMPLEMENTATION STRATEGY

The original statement of asset need presented three options for implementing the PS012 controls. The recommended option for the first two years of the program was a single additional relay aligned with the network future strategy. It has been demonstrated under PS012 PD1552 that the costs of total panel replacement is much lower cost than anticipated. A financial and outcome based assessment has been performed and it is now recommended that complete panel replacement be implemented (refer Appendix C). The replacement of early model numerical relays provides a net financial benefit and the replacement of electromechanical relays can provide benefits of full range protection duplication and reduced primary busbar clearance times.

The recommended implementation strategy for the remaining years of PS012 is below.

| Summary of Recommended Implementation Strategy | |
|---|---|
| Cost | $10.6 million (+ $0.9 million contingency)<br>Refer site list at Appendix A. |
| Relay technology | Duplicate numerical relay with panel replacement where required.<br>Refer supporting information at Appendix C.<br><br>At least one of the relays to be capable of VT measurement and advanced fault recording capability. |
| Relay communications | Ethernet communications with IEC61850 protocol.<br>SCADA system upgrades as required to accommodate.<br>Refer supporting information at Appendix D. |
| Circuit breaker fail | Initiation of CB Fail tripping from all in scope feeders.<br>CB fail multi-trip to trip all CBs on the relevant bus section. |
| Core balance current transformers | As per schedule at Appendix B. |
| Advanced fault reporting | Relays to provide advanced fault information to SCADA (including fault magnitude, phases, and distance where applicable).<br><br>Remote retrieval of COMTRADE disturbance files from protection relays to *SCADA Web* where possible. |

## 4.0 RECOMMENDATIONS

It is recommended that a business case be developed for the approval to spend $11.5 million across the 2017/18 to 2020/21 financial years. This will see these works applied to replace 303 distribution feeder protection systems across 31 sites. In summary, the upgrade consists of:

- Implement modern feeder protection systems with voltage measurement and Ethernet communications capability, including the necessary SCADA system upgrades required to accommodate the installation.
- Retrofit core balance CT's at sites with the highest proportion of network bushfire risk, where it is cost justified.
- Install circuit breaker failure systems to improve safety, compliance and reliability.

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# 5.0 APPENDIX A (Site list and priority order)

| Substation | Fdrs | UG (km) | OH (km) | % total network bushfire risk | NPV Benefit (bushfire - modern relay) | Possible Benefit (bushfire - core balance) | Cost of CBCT installation (estimate) | Reliability impact of selectable 1A CBCT setting | Possible Net Benefit of CBCT Installation | CBCT Justified | NPV benefit (bushfire - core balance CT) | % program arc flash risk (UG) | NPV (arc flash) | % network fatal contact (OH) | NPV (fatal contact) | Total NPV benefits | Site Cost | Cost benefit ratio | Future PD Priority |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rooty Hill | 13 | 66.96 | 41.54 | 0.01% | $704 | $723 | $ 39,000 | $ 23,573 | -$61,850.27 | N | $0.00 | 3.70% | $ 1,699,504 | 1.93% | $ - | $ 1,700,208 | $ 397,600 | 4.3 | 1 |
| Macquarie Fields | 11 | 49.97 | 29.79 | 0.09% | $6,159 | $6,324 | $ 33,000 | $ 19,947 | -$46,622.51 | N | $0.00 | 2.76% | $ 1,268,308 | 1.39% | $ - | $ 1,274,467 | $ 349,800 | 3.6 | 2 |
| West Castle Hill | 21 | 67.44 | 9.01 | 0.24% | $15,768 | $16,192 | $ 63,000 | $ 38,080 | -$84,887.88 | N | $0.00 | 3.73% | $ 1,711,661 | 0.42% | $ - | $ 1,727,429 | $ 607,760 | 2.8 | 3 |
| Lithgow | 10 | 24.03 | 504.56 | 2.29% | $152,925 | $157,036 | $ 32,000 | $ 18,133 | $106,902.90 | Y | $157,036.23 | 1.33% | $ 609,765 | 2.32% | $ 5,894 | $ 925,620 | $ 362,150 | 2.6 | 4 |
| Cambridge Park | 9 | 28.33 | 6.38 | 0.01% | $802 | $824 | $ 27,000 | $ 16,320 | -$42,496.20 | N | $0.00 | 1.57% | $ 718,871 | 0.30% | $ - | $ 719,673 | $ 294,500 | 2.4 | 5 |
| Moss Vale | 7 | 16.63 | 422.66 | 1.49% | $99,675 | $102,354 | $ 21,000 | $ 12,693 | $68,661.13 | Y | $102,354.46 | 0.92% | $ 422,160 | 2.32% | $ 5,894 | $ 630,083 | $ 268,300 | 2.3 | 6 |
| Kingswood | 13 | 40.22 | 51.12 | 0.08% | $5,128 | $5,266 | $ 39,000 | $ 23,573 | -$57,307.75 | N | $0.00 | 2.22% | $ 1,020,783 | 2.32% | $ - | $ 1,025,911 | $ 445,100 | 2.3 | 7 |
| Plumpton | 13 | 40.48 | 48.17 | 0.01% | $468 | $481 | $ 39,000 | $ 23,573 | -$62,092.81 | N | $0.00 | 2.24% | $ 1,027,306 | 2.24% | $ - | $ 1,027,774 | $ 447,600 | 2.3 | 8 |
| Riverstone | 10 | 15.46 | 133.72 | 5.28% | $353,399 | $362,899 | $ 158,000 | $ 18,133 | $186,765.69 | Y | $362,899.02 | 0.85% | $ 392,263 | 2.32% | $ 5,894 | $ 1,114,455 | $ 537,650 | 2.1 | 9 |
| Cattai | 5 | 6.31 | 264.11 | 1.88% | $125,641 | $129,018 | $ 15,000 | $ 9,067 | $104,951.30 | Y | $129,017.96 | 0.35% | $ 160,220 | 2.32% | $ 5,894 | $ 420,772 | $ 214,060 | 2.0 | 10 |
| Dundas | 15 | 33.03 | 78.27 | 0.00% | $5 | $5 | $ 45,000 | $ 27,200 | -$72,194.92 | N | $0.00 | 1.83% | $ 838,382 | 2.32% | $ - | $ 838,387 | $ 447,900 | 1.9 | 11 |
| Newton | 10 | 23.14 | 21.49 | 0.00% | $213 | $218 | $ 30,000 | $ 18,133 | -$47,915.11 | N | $0.00 | 1.28% | $ 587,329 | 1.00% | $ - | $ 587,542 | $ 328,150 | 1.8 | 12 |
| North Wollongong | 6 | 15.29 | 21.96 | 0.00% | $0 | $0 | $ 18,000 | $ 10,880 | -$28,880.00 | N | $0.00 | 0.85% | $ 387,924 | 1.02% | $ - | $ 387,924 | $ 224,050 | 1.7 | 13 |
| Hazelbrook | 6 | 12.00 | 66.77 | 0.88% | $58,586 | $60,161 | $ 20,000 | $ 10,880 | $29,281.12 | Y | $60,161.12 | 0.66% | $ 304,654 | 2.32% | $ 5,894 | $ 429,295 | $ 248,850 | 1.7 | 14 |
| Katoomba | 8 | 16.08 | 81.88 | 0.43% | $28,883 | $29,659 | $ 24,000 | $ 14,507 | -$8,847.35 | N | $0.00 | 0.89% | $ 408,151 | 2.32% | $ - | $ 437,034 | $ 272,810 | 1.6 | 15 |
| Blaxland | 9 | 11.16 | 59.03 | 1.71% | $114,324 | $117,397 | $ 31,000 | $ 16,320 | $70,076.67 | Y | $117,396.67 | 0.62% | $ 283,335 | 2.32% | $ 5,894 | $ 520,949 | $ 337,700 | 1.5 | 16 |
| Moorebank | 12 | 27.16 | 42.58 | 0.01% | $357 | $366 | $ 36,000 | $ 21,760 | -$57,393.91 | N | $0.00 | 1.50% | $ 689,329 | 1.98% | $ - | $ 689,685 | $ 460,950 | 1.5 | 17 |
| Seven Hills | 14 | 24.28 | 40.84 | 0.00% | $0 | $0 | $ 42,000 | $ 25,387 | -$67,386.67 | N | $0.00 | 1.34% | $ 616,186 | 1.90% | $ - | $ 616,186 | $ 428,750 | 1.4 | 18 |
| Lennox | 13 | 22.68 | 10.16 | 0.00% | $42 | $43 | $ 39,000 | $ 23,573 | -$62,530.51 | N | $0.00 | 1.25% | $ 575,528 | 0.47% | $ - | $ 575,570 | $ 402,600 | 1.4 | 19 |
| Horsley Park | 9 | 16.36 | 64.74 | 0.38% | $25,589 | $26,276 | $ 27,000 | $ 16,320 | -$17,043.60 | N | $0.00 | 0.90% | $ 415,080 | 2.32% | $ - | $ 440,668 | $ 321,500 | 1.4 | 20 |
| Blackmans Flat | 5 | 9.44 | 233.95 | 0.31% | $21,079 | $21,645 | $ 15,000 | $ 9,067 | -$2,421.43 | N | $0.00 | 0.52% | $ 239,657 | 2.32% | $ - | $ 260,736 | $ 191,400 | 1.4 | 21 |
| Port Central | 6 | 12.11 | 27.78 | 0.00% | $0 | $0 | $ 18,000 | $ 10,880 | -$28,880.00 | N | $0.00 | 0.67% | $ 307,293 | 1.29% | $ - | $ 307,293 | $ 234,550 | 1.3 | 22 |
| Cabramatta | 11 | 18.45 | 32.25 | 0.02% | $1,083 | $1,112 | $ 33,000 | $ 19,947 | -$51,834.68 | N | $0.00 | 1.02% | $ 468,249 | 1.50% | $ - | $ 469,332 | $ 393,800 | 1.2 | 23 |
| Prospect | 11 | 17.63 | 55.46 | 0.01% | $498 | $512 | $ 33,000 | $ 19,947 | -$52,434.95 | N | $0.00 | 0.98% | $ 447,413 | 2.32% | $ - | $ 447,911 | $ 396,300 | 1.1 | 24 |
| Kenny Street | 8 | 12.13 | 2.31 | 0.00% | $0 | $0 | $ 24,000 | $ 14,507 | -$38,506.67 | N | $0.00 | 0.67% | $ 307,928 | 0.11% | $ - | $ 307,928 | $ 275,350 | 1.1 | 25 |
| Sherwood | 12 | 18.39 | 48.35 | 0.00% | $0 | $0 | $ 36,000 | $ 21,760 | -$57,760.00 | N | $0.00 | 1.02% | $ 466,752 | 2.25% | $ - | $ 466,752 | $ 421,950 | 1.1 | 26 |
| Inner Harbour | 10 | 13.57 | 0.44 | 0.00% | $26 | $27 | $ 30,000 | $ 18,133 | -$48,106.20 | N | $0.00 | 0.75% | $ 344,500 | 0.02% | $ - | $ 344,526 | $ 314,850 | 1.1 | 27 |
| Woodpark | 9 | 13.39 | 12.11 | 0.00% | $0 | $0 | $ 27,000 | $ 16,320 | -$43,320.00 | N | $0.00 | 0.74% | $ 339,754 | 0.56% | $ - | $ 339,754 | $ 316,500 | 1.1 | 28 |
| North Rocks | 9 | 13.36 | 31.71 | 0.00% | $0 | $0 | $ 27,000 | $ 16,320 | -$43,320.00 | N | $0.00 | 0.74% | $ 339,068 | 1.47% | $ - | $ 339,068 | $ 324,000 | 1.0 | 29 |
| Luddenham | 4 | 4.68 | 88.80 | 0.90% | $60,135 | $61,751 | $ 71,000 | $ 7,253 | -$16,501.92 | N | $0.00 | 0.26% | $ 118,674 | 2.32% | $ - | $ 178,809 | $ 181,450 | 1.0 | 30 |
| Appin | 4 | 2.59 | 74.55 | 0.42% | $28,201 | $28,959 | $ 12,000 | $ 7,253 | $9,705.45 | Y | $28,958.78 | 0.14% | $ 65,682 | 2.32% | $ 5,894 | $ 128,735 | $ 170,450 | 0.8 | 31 |
| Greystanes | 12 | 7.02 | 46.80 | 0.01% | $470 | $483 | $ 36,000 | $ 21,760 | -$57,277.47 | N | $0.00 | 0.39% | $ 178,239 | 2.18% | $ - | $ 178,709 | $ 385,950 | 0.5 | 32 |
| Glossodia | 6 | 1.99 | 192.73 | 0.92% | $61,666 | $63,323 | $ 62,000 | $ 10,880 | -$9,556.62 | N | $0.00 | 0.11% | $ 50,429 | 2.32% | $ - | $ 112,095 | $ 279,510 | 0.4 | 33 |
| Portland | 3 | 0.98 | 88.84 | 0.10% | $6,975 | $7,162 | $ 9,000 | $ 5,440 | -$7,277.93 | N | $0.00 | 0.05% | $ 24,923 | 2.32% | $ - | $ 31,897 | $ 143,600 | 0.2 | 34 |
| Berrima Junction | 1 | 0.45 | 0.00 | 0.00% | $5 | $5 | $ 3,000 | $ 1,813 | -$4,808.18 | N | $0.00 | 0.02% | $ 11,294 | 0.00% | $ - | $ 11,299 | $ 89,800 | 0.1 | 35 |

The recommendation is made to implement the scope of PS012 at all sites listed above with the exception of Greystanes, Glossodia, Portland and Berrima Junction zone substations. These four sites have a cost benefit ratio below one with inclusion of safety disproportionality. While Appin ZS has a ratio below 1.0 (factor is 0.8) the NPV cost to Endeavour Energy to realise the substantial benefits of PS012 is only $10,400 per feeder which achieves both the un-costed benefits as well as protection refurbishment for the existing scheme (which will be approximately 37 years old). Appin ZS also has limited coverage by field reclosers, moderate contribution to network bushfire risk and cost justified core balance installation. The recommendation is made to implement at Appin ZS.

# 6.0 APPENDIX B (Site list for core balance CT installation under PS012)

The following sites shall have core balance CTs installed under the PS012 program where cost justified:

Appin ZS
Blaxland ZS
Bringelly ZS
Cattai ZS
Cranebrook ZS
Emu Plains ZS
Hazelbrook ZS
Kellyville ZS
Kenthurst ZS
Kurrajong ZS
Lithgow ZS
Mittagong ZS
Moss Vale ZS
Riverstone ZS

The site list made above is a high level list and not all feeders at every site will have core balance CTs installed. The feeders selected for installation are at the discretion of Protection Design and will be listed in the Protection and Indication Equipment Schedule (PIES).

There may also be limited sites within the scope of PS012 but not listed above where it may be cost justified completing a CBCT installation. These individual feeders will be assessed by Protection Design and where applicable be listed in the PIES for the PS012 works.

The core balance CT installation shall normally be operated with a SEF pickup setting of 4A.

A temporary, SCADA selectable, setting of 1A shall be made available for use on total fire ban days.

The installation of core balance CT at sites outside of PS012 will be subject to a cost benefit evaluation performed by Protection Design.

Note that both Luddenham ZS and Glossodia ZS had previously appeared on this list, but re-costing of the core balance CT at these locations has been evaluated as non-cost justified.

# 7.0 APPENDIX C (Relay Replacement Considerations)

The relays targeted for replacement in the PS012 program include electromechanical CDG relays as well as early generation static or numerical relays such as the SPAJ, 2DCC, MCGG, and KCGG series relays.

The following two sections present considerations to replacing the remaining relay in opposition to the single relay replacement strategy for originally proposed PS012.

**<u>Considerations for replacement of early generation numerical or static relay</u>**

The following considerations are relevant in the assessment of replacing a remaining numerical or static relay:

1) The anticipated lifespan of the numerical or static relays is approximately 20 years. The remaining PS012 target sites include relays nearing 15 or more service years.

2) It was anticipated in the original SAN that replacement of the duplicate relay would add more than $10,000 per feeder. It has been ascertained through the implementation of some feeders under PS012 PD1552 that the cost associated with replacing the relay alongside the other works of PS012 is much cheaper at around $3,000.

3) A financial assessment replacing the numeric or static relay as part of PS012 (cost $3,000), rather than toward the relay end of life (at a cost of $16,000 in today's terms) provides cost synergies and a present value saving of approximately $7,300 per feeder.

4) The protection duplication by use of a modern relay, as opposed to maintaining the early numerical relay, provides additional protection benefits, such as duplication of the sensitive earth fault function and typically a larger number of instantaneous overcurrent elements.

The variations in the above considerations have been captured in the below Monte Carlo analysis shown at Figure A5.1. The results support full panel replacement with a positive NPV outcome.

**<u>Considerations for replacement of electromechanical relay</u>**

The following considerations are relevant in the assessment of replacing the remaining electromechanical relay:

1) Full range protection duplication and characteristic matching is not achieved.

2) Inability to achieve full improvements in clearing times due to higher grading margins.

3) Reduced busbar primary clearance times.

The above benefits are detailed in the paragraphs below. Additionally there are benefits of improved familiarity (for protection technicians), and the complete renewal of non-relay hardware such as wiring and links may also prevent age related issues (noting that the typical age of such hardware is 30 to 50 years).

### 7.1.1 Full range protection duplication and characteristic matching

Electromechanical relays are manufactured with a single fixed time characteristic. Modern numerical relays provide multiple characteristics, which are fully selectable and independently settable.

When an electromechanical relay is installed alongside a modern numerical relay the two characteristics cannot be perfectly matched. Protection designers must make a best judgement about how best to align the two characteristics.

Electromechanical relays also do not provide guaranteed timing performance below a certain point (typically twice the pickup setting) while a modern numerical relay provides predictable timing and dependable operation in this range.

Figure A5.2 below demonstrates the lack of full protection redundancy for some lower fault currents (between 400A and 800A) and the difference in time characteristic across the entire current range.

### 7.1.2 Clearance time improvements not realised

The construction and operating tolerances of electromechanical relays required higher grading margins be used between devices. Typical electromechanical grading margins are around 400ms. Modern numerical relays provide more accurate timing, and can be set with grading margins at 300ms or lower. Where feeder protection relays are time graded with downstream distribution substation protection, electromechanical relays must be slowed more so than numerical relays. This further exacerbates the protection duplication issue above.

Figure A5.3 below demonstrates how an electromechanical relay must be slowed in comparison with a modern numerical relay when grading with downstream customer protection.

### 7.1.3 Primary protection of 11kV busbar

The primary protection for the 11kV busbar protection at many older substations is the transformer 11kV overcurrent. As a consequence to the above issues (characteristic matching and grading margins) the transformer 11kV overcurrent must be slowed to fully grade with the electromechanical relay.

Figures A5.4 and A5.5 below demonstrate the difference in clearance times for a busbar fault in two scenarios. The first scenario is a substation with feeder protection which still includes electromechanical relays. The second scenario is for a substation with feeder protection consisting of duplicate modern numerical relays. In this example the clearance time for a 13kA fault on the 11kV busbar is improved from around 800ms to around 470ms by having duplicate numerical relays on the outgoing feeder panels. Fault energy is reduced by around 40%, and the substation damage will be reduced significantly.

## PS012 relay replacement comparison
## Duplicate replacement VS Single replacement and delayed second relay replacement

| Certain or fixed inputs | | |
|---|---|---|
| NPV discount rate | 6.00% | |

| Uncertain inputs | Sample values | P5 | P50 | P95 | Theomin | Theomax | Truncmin | Truncmax |
|---|---|---|---|---|---|---|---|---|
| **Panel replacement costs** | | | | | | | | |
| Complete panel replacement cost (2 relays under PS012) | $28,816 | $26,000 | $29,000 | $31,000 | $22,888 | $31,602 | $0 | $35,000 |
| **Relay only replacement costs** | | | | | | | | |
| Initial relay replacement cost (Single PS012 relay install) | $25,816 | $23,000 | $26,000 | $28,000 | $19,888 | $28,602 | $0 | $35,000 |
| Time before next renewal (years) | 8 | 3 | 7 | 15 | 2 | 26 | 0 | 40 |
| Cost of next renewal (Single new relay) | $15,920 | $10,000 | $15,000 | $25,000 | $9,163 | $38,692 | $0 | $50,000 |

| Intermediate calculations | |
|---|---|
| Nil | |

| | | | 0.01 | 0.05 | 0.5 | 0.95 | 0.99 | |
|---|---|---|---|---|---|---|---|---|
| **Outputs** | **Sample values** | | **P1** | **P5** | **P50** | **P95** | **P99** | **Mean** |
| NPV of panel replacement option | -$28,816 | | -$31,353 | -$31,000 | -$29,000 | -$26,000 | -$24,926 | -$28,816 |
| NPV of relay replacement option | -$35,959 | | -$47,583 | -$43,730 | -$35,685 | -$30,420 | -$28,610 | -$36,193 |
| Difference of NPV's (Cost of panel replacement) | $7,143 | | -$984 | $1,034 | $6,925 | $15,304 | $19,316 | $7,377 |

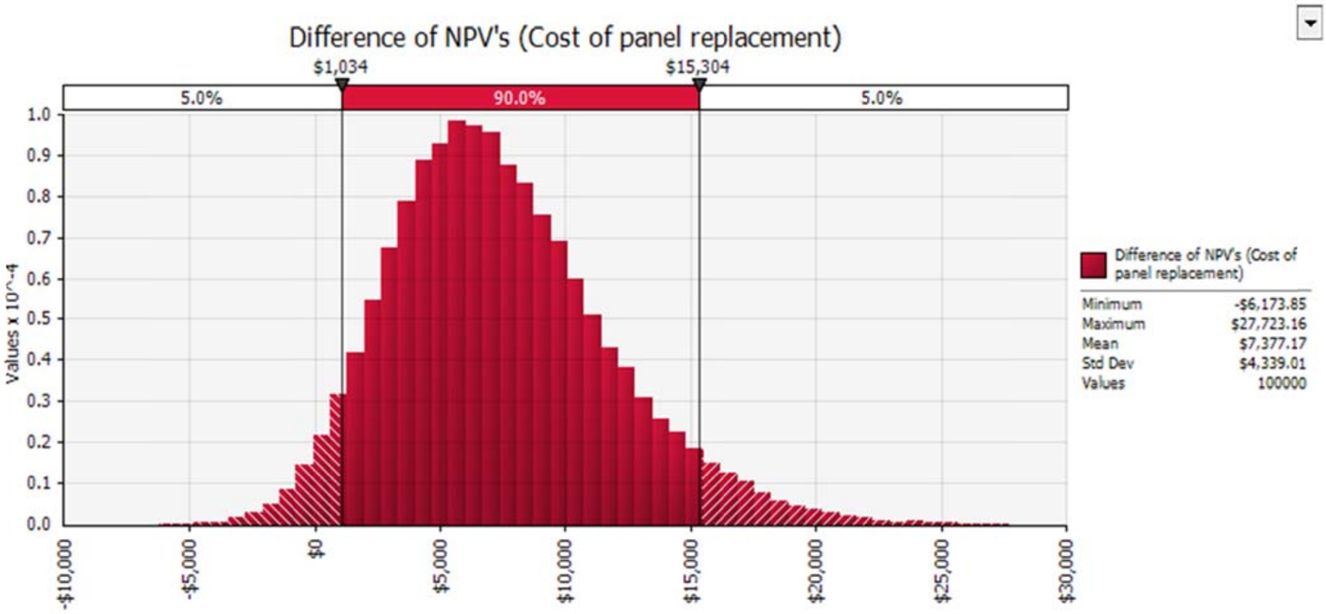



**Figure A5.1: Likely cost benefit outcomes of early replacement of second numerical relay**

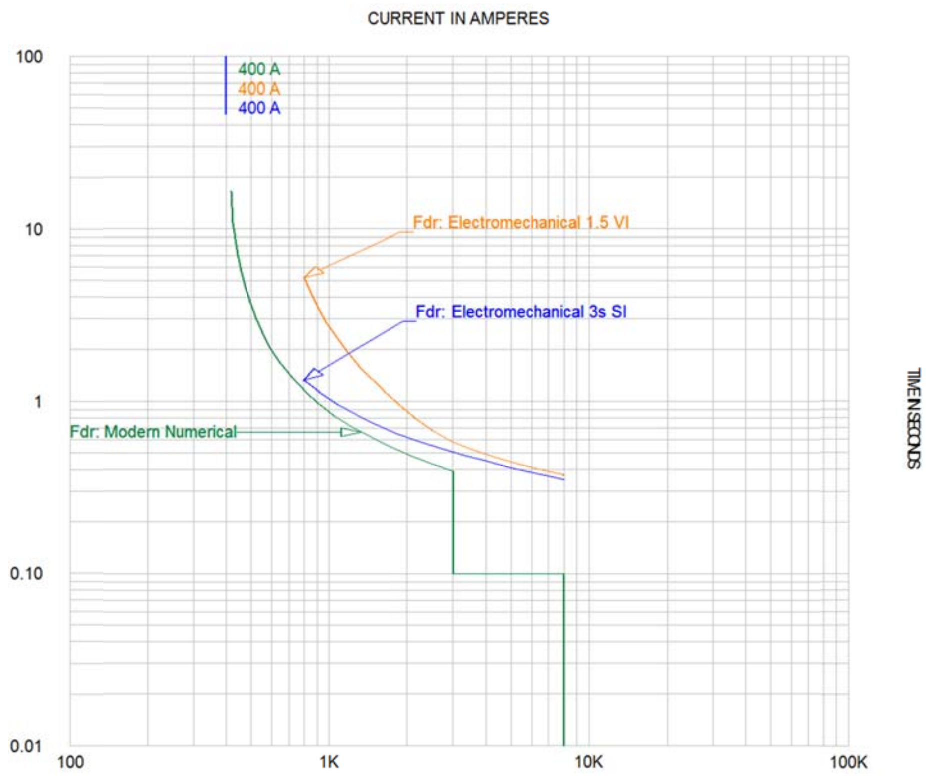



Figure A5.2: Differences in time-current characteristic for modern numerical relay (with preferred curve selected) and electromechanical relay. In this example, the electromechanical relay does not provide guaranteed performance below 800A.

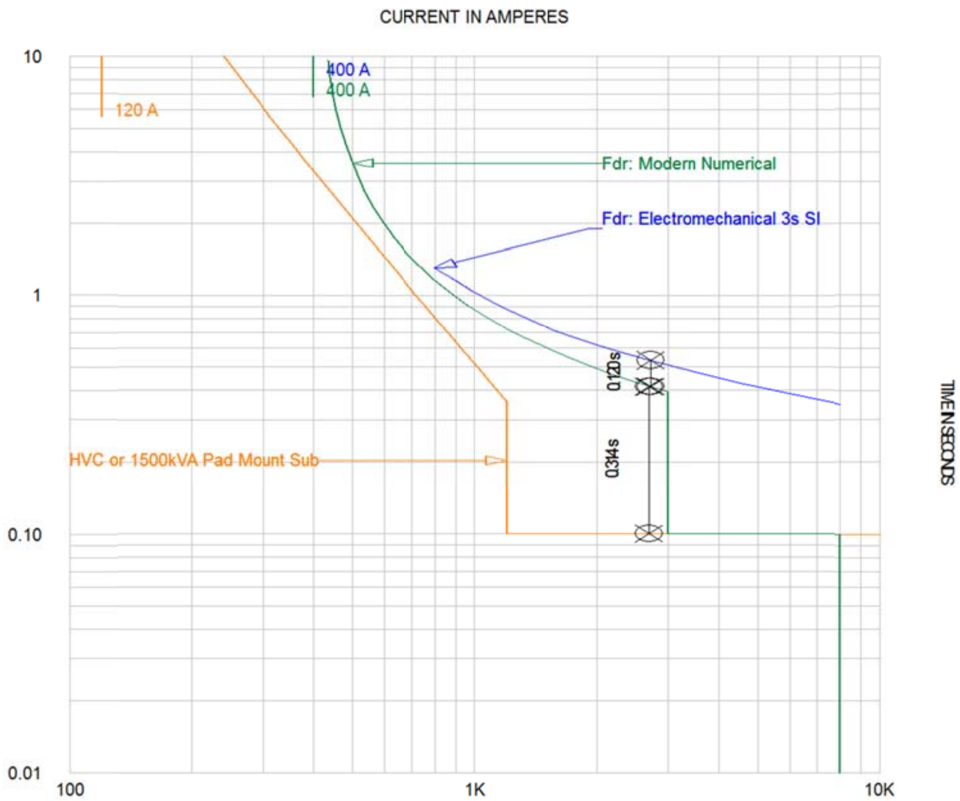



Figure A5.3: Electromechanical relay must be no closer than 400ms to downstream protection. The modern numerical may be set with grading margin of 300ms.

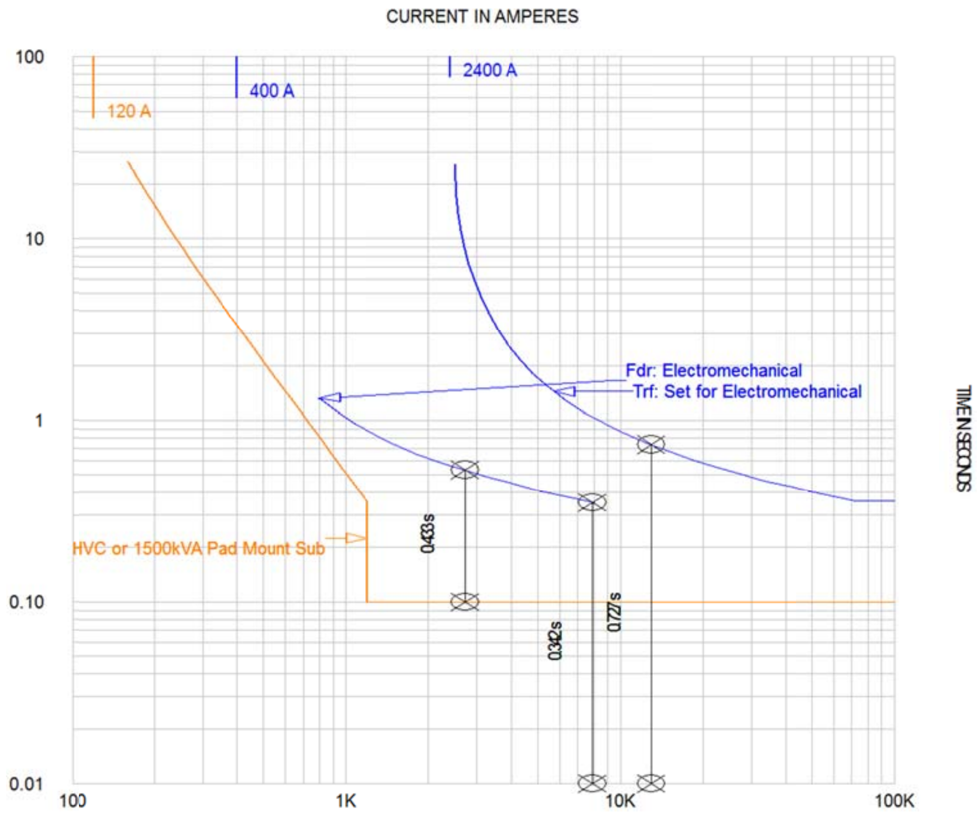



Figure A5.4: Transformer overcurrent operating times for 11kV busbar fault.
The transformer relay is time graded with the slowest (electromechanical) feeder relay.

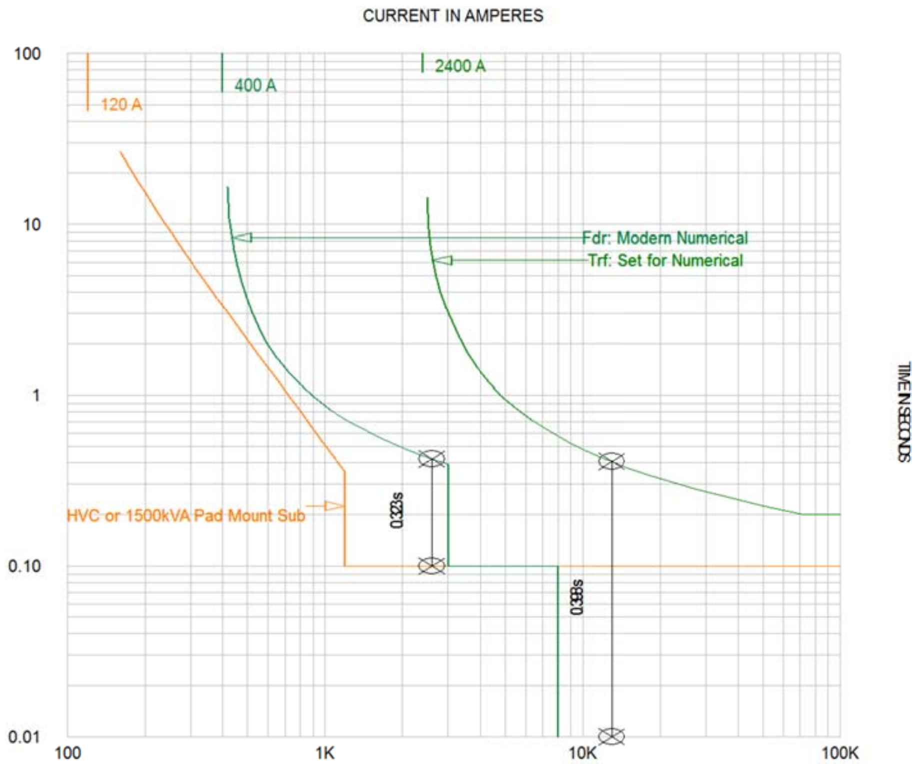



Figure A5.5: Transformer overcurrent operating times for 11kV busbar fault.
The transformer relay is time graded with the slowest (numerical) feeder relay.

# 8.0 APPENDIX D (Ethernet Communications)

The strategy for using Ethernet communications between SCADA equipment and protection relays was first implemented in PS012 PD1552. In line with the original PS012 SAN the post implementation review supports Ethernet as the preferred communication medium moving forward for all protection and SCADA communication.

The implementation of the first two years of PS012 has provided much learning in both the design and implementation of Ethernet communications. Even in the infancy of implementation, the simplicity of installation and reliability of this medium in practice are very apparent. In addition to the robustness, self-monitoring benefits of the network it has been possible to implement advanced fault reporting to SCADA and remote retrieval of comprehensive fault records.

The following table provides some of the considerations and high level costs included in a post implementation review and assessment of Ethernet Communications for protection relay SCADA communications.

Two physical mediums are compared below, RS485 serial communication with copper based Ethernet communications. These options are then assessed for costs and benefits when coupled with the two RTU types typically found in Endeavour Energy zone substations (the MD1000 and MD300 products from CGI).

It should be noted that the below costings are prepared for IEC 61850 compliant communications with capability limited to SCADA and non-time-critical control only. These costs are not representative of the requirements for full process bus or time critical operations.

| | RS485 | | | ETHERNET | | |
|---|---|---|---|---|---|---|
| | | **MD1000 site** | **MD300 site** | | **MD1000 site** | **MD300 site** |
| Hardware costs | Terminal server (RS400) | $4,000 | $0 | **Ethernet only costs** | | |
| | Core switch (RS2100) | $6,500 | $0 | Additional cost per relay | $500 | $500 |
| | | | | Switch (unmanaged) | $1,000 | $1,000 |
| | | | | Core Switch (MOXA) | $2,500 | $0 |
| | | | | **DNP3 specific costs** | | |
| | | | | Terminal server (MOXA) | $750 | $0 |
| | | | | **IEC 61850 specific costs** | | |
| | | | | Sub-RTU MD300 | $2,500 | $0 |
| | | | | IEC 61850 RTU licence | $2,500 | $2,500 |
| SCADA Engineering | Design duration | Base cost | Base cost | Design duration (DNP3) | Base cost | Base cost |
| | | | | Design duration (IEC 61850) | Base cost + 0.5day/relay | Base cost |
| Installation | RS485 physical medium not fully standard.<br>Efforts to commission are often iterative, some installations requiring resistors and/or capacitors be installed. | | | Ethernet physical medium is highly standard.<br>Ethernet leads can be purchased pre-terminated for improved speed of installation. | | |
| Engineering rollback costs | | | | The preferred protocol for Ethernet communications is IEC 61850 as development of this protocol is already implemented. The costs below are once off costs associated with implementing a solution for DNP3 over Ethernet. | | |
| | | | | Prot. Dev. | 2 weeks | 8000 |
| | | | | SCADA Dev. | 2 weeks | 8000 |
| Indicative costs | Typical installation | $10,500 / site | $0 | Typical install using 61850 | $13,500 | $8,500 |
| Qualitative costs and benefits | - Watts/VARs measurements capped to 1 in 60 seconds.<br>- RS485 un-monitored. Does not facilitate online testing.<br>- Line duplication required where multiple relay vendors on site.<br>- Downloading of fault records is not possible with existing infrastructure.<br>- Control functionality limited.<br>- Not "future proof": vendor support is weaning: for example Trf. WTI no DNP3 support.<br>- Comm failures are high. P&C Tech call outs are common - refer to Cranebrook, Oakdale, Mamre and Mt Druitt as example cases. No similar failures reported on PS012 sites.<br>- "Daisy chain" const. is susceptible to multiple concurrent relay comm failures | | | - Watts/VARs measurements capped to 1 in 10 seconds.<br>- Ethernet is 'plug and play', and is self monitoring.<br>- Ethernet link integrity is monitored; can be tested (ping).<br>- Line duplication not required. Complete inter-vendor compatibility.<br>- Fault record retrieval is possible with base hardware on Ethenet<br>- Cyber security requires attention (similar to MPLS security strategies)<br>- Control functionality improvements possible over Ethernet (due to reliability, speed)<br>- "Future proof": flexibility to append features without bandwidth constraints(SEF pickup, SEF analogues)<br>- "Future proof": movement of control functionalities to communications bus can improve network reliability (Parklea loss of load was via energisation of CBFail link from control wiring which could potentially be moved to robust Ethernet networks)<br>- IEC 61850 has unique in-built security. Reports / subscriber model.<br>- Ethernet provides SNTP time synching between devices. | | |

**Summary**

There is a nominal increase in cost to implement an Ethernet physical network with IEC 61850 protocol for both MD1000 and MD300 sites.
Ethernet communications provides extensive qualitative benefits over RS485 communications.

Notes and analysis assumptions applicable to the above table:
- The term 'Base Cost' reflects the cost to implement a SCADA design for a simple numerical relay. The term is used to indicated where net cost change is nil.
- Typical installation is reflective of PS012 installations, example up to 10 relays.
- RS485 and Ethernet comparison above is in the context of PS012.
- IEC61850 elements below is a "SCADA" implementation only. Additional costs outsidie of below is require for process bus or time-ciritical operation
- Analysis assumes the existing SCADA infrastructure is CGI. Cost variations for ABB type sites not considered (limited number of sites).

# 9.0 APPENDIX E (Economic cost of bushfire)

There is no single recommended value for the economic cost of bushfire in Australia. However there are a number of well recognised sources. The most prominent being a report prepared by the Bureau of Transport Economics (BTE) “Report 103: Economic costs of natural disasters in Australia” (January 2001).

Following the Victorian Bushfires of 2009, regulation changes in Victoria were proposed. A Regulatory Impact Statement was prepared by Acil Allen Consulting in November 2015 (“Report to Department of Economic Development, Jobs, Transport and Resources. Regulatory Impact Statement: Bushfire Mitigation Regulations Amendment”). The RIS includes an economic cost of bushfire – a value based on the BTE report with two adjustments: (1) adjustment to 2014 $, and; (2) applying a different value of statistical life. The BTE report uses a VSL of $1.3M, where the RIS applies a value of $4.2M – in line with the Australian Government’s Office of Best Practice Regulation. These two adjustments are then condensed to a single factor of 2.5x - that is, the RIS estimates the cost of bushfire to be 2.5x the cost of bushfire estimated in the BTE report.

Applying a similar methodology to that used by RIS to the BTE Report’s value of NSW bushfire cost we obtain a value of $42 million ($16.8M x 2.5). This value represents the likely average annual historical cost of bushfires in NSW (in 2014 dollars).

The RIS also notes from the Royal Commission that only around 1.5% of all bushfire ignitions is due to electricity assets, but also notes that these ignitions were most likely to occur in extreme conditions where the consequences are likely to be disastrous. With other considerations (refer page 38 of the RIS), it is suggested that “an indicative estimate of the proportion of major bushfire costs likely to be attributable to electricity asset failures in the future, in the absence of specific policy action, of around 50 per cent is considered reasonable.” Inclusion of this factor provides an indicative annual average cost of major bushfires in NSW attributed to electricity assets be $21 million per annum.

Given that approximately 40% of all fatalities in NSW has occurred in Endeavour Energy’s network area (irrespective of cause), the total economic cost of bushfires applicable to Endeavour Energy’s network area, which are caused by electricity assets is taken to be 40% of $22 million which is $8.8 million per annum in today’s terms. This includes the valuation of safety risk.

The total economic <u>value of current and future existing risk</u> (including safety risk) of bushfires relating to Endeavour Energy’s network assets is taken to be $8.8 million per annum.

# 10.0 APPENDIX F (Original SAN Document)

STATEMENT OF ASSET NEED

# DISTRIBUTION FEEDER PROTECTION MODERNISATION

## SARP PS012

Revision 1 (May 2015)

**Matthew Browne**

Protection Manager - Secondary Systems

CONTENTS

# 1.0 EXECUTIVE SUMMARY

This statement of asset need has been written to justify a new protection SARP program (nominally PS012). The program will see the replacement of old technology protection relays installed on distribution feeders with modern microprocessor protection relays. This modern technology will result in substantial benefits to safety, some reduction in expenditure, and several other benefits. The program will also improve safety, reliability, and compliance with more sensitive earth fault detection through the installation of core balance current transformers and through the introduction of redundancy.

The total cost of the program is estimated to be $19.7 million (plus $1.7 million contingency) over 6 years commencing in 2015/16 and the program will cover 623 feeders across 66 zone substation sites. **This statement of asset need recommends that a business case be developed to gain approval for $7.0 million total for the 2015/16 and 2016/17 years for the implementation of these works on 241 feeders across 26 sites.**

## 1.1 Primary benefits

The key benefits of the program stem from a substantial reduction in high voltage electrical fault clearance times, an increase in the sensitivity of earth fault protection, and from the provision of redundancy through duplication of protection systems, and from the inclusion of circuit breaker failure systems. The primary benefits include:

- **A material reduction in the impact of uncontrolled discharge of electricity accidents, particularly arc flash accidents.** This control will reduce the arc flash energy by a factor of around 3 at high fault levels on most distribution feeders, substantially reducing the severity of injurious arc flash accidents which at present happen at a rate of 1-2 occurrences per annum and involve both employees, contractors, ASP's and members of the public. A quantitative safety risk cost benefit analysis has been applied based on international best practice. An assessment suggests that this risk control would have to cost greater than $134 million to be considered grossly disproportionate. A detailed safety QRA has been included in the appendix of this report.
- **An increase in the likelihood of high impedance faults, such as lines on the ground and tree contact, being detected, thus reducing the risk of fatal contact.** Core balance CT's will increase the sensitivity to high impedance faults by a factor of 4 with a reduction in the detection level from 4A to 1A. Modern relays will also allow a substantially lower threshold for normal earthfault protection as well. The program will also see the installation of SEF on underground feeders which can potentially feed into overhead systems. An assessment suggests that this risk control would have to cost greater than $49.5 million to be considered grossly disproportionate. A detailed safety QRA has been included in the appendix of this report.
- **A reduction in the likelihood of bushfire ignition due to reduced clearance times and more sensitive fault detection.** An assessment suggests that this risk control would have to cost greater than $17.7 million to be considered grossly disproportionate. A detailed safety QRA has been included in the appendix of this report.
- **A lower risk of non-operation of feeder protection and minimisation of the subsequent reliability impact** due to duplication and the addition of circuit breaker failure systems. This has been assessed to be necessary to align to industry practice, Endeavour Energy Standards, and in order to reduce feeder fault risk to be ALARP.

## 1.2 Secondary benefits

- A substantial reduction in the gross risk and reduction in costs associated with achieving earthing system compliance. The Endeavour Energy cost saving is likely to be substantial, but is very difficult to quantify. Savings to land developers is estimated to be in the order of $0.5 million per annum for a total of $11.5 million ($5.5M NPV) in avoided costs over the 20 year life of the new relays. This value has not been factored into the cost benefit analysis.
- A substantial reduction in the cost associated with the replacement of fault rating exceeded conductors. The cost saving to Endeavour Energy is estimated to be in the order of $3.5 million over the next 10 years by way of avoiding the replacement of fault rating exceeded conductors.
- A reduction in through fault energy, reducing the cumulative damage to equipment such as conductors and transformers, leading to longer equipment lives and better reliability (e.g. reduction in overhead bond failures leading to lines on the ground).
- Remote indication of fault type and fault current. This can assist in the assessment of risk and the locating of permanent faults on the network, thus potentially reducing outage times.
- The opportunity to reduce maintenance costs to reduce CB maintenance by basing it on the actual fault currents and phases involved in the fault.
- Provides detailed fault records, assisting with the investigation of incidents and helping to permit a better understanding of events which can lead to appropriate choice of remedial actions and can help enhance safety and reliability in the future.
- An improvement in power quality (reduced dip times). This has the potential to reduce impacts on and reduce complaints from sensitive customers.

# 2.0 ELECTRICAL ACCIDENTS AND LOWER FAULT CLEARANCE TIMES

## 2.1 Arc flash accidents

Arc flash is one of the most notable safety hazards in the electrical industry. There have been at least 7 persons injured, 5 seriously, from arc-flash burns on the Endeavour Energy HV distribution network in the last 5 years (2010 to 2014 inclusive). A summary of these occurrences is detailed in the table below.

| Date | Location | Activity | Fault details | Injuries |
|---|---|---|---|---|
| 30/10/2013 | Eastern Creek ZS (near to the substation) | Cutting cable | 8kA (estimated) 0.5s (estimated) | 2 (seriously injured) |
| 24/10/2013 | Northmead (Substation 3015) | Cutting cable | 8kA (calculated) 2.3s (measured) | 1 (seriously injured) |
| 26/07/2012 | West Liverpool ZS (near to the substation) | Cutting cable | 5.8kA (measured) 0.4s (measured) | 1 (seriously injured) |
| 15/05/2012 | Kellyville | Cutting cable | 1.2kA (calculated) 1.2s (calculated) | 1 (minor injuries) |
| 11/04/2012 | Merrylands | Cutting cable | Unknown | 1 (hospitalised unknown extent of injuries) |
| 14/10/2010 | Penrith (Substation 18010) | Switching | 5.2kA (calculated) 0.6s (calculated) | 1 (seriously injured) |

These occurrences often lead to a long and painful recovery, lasting physical quality of life impacts, and a high incidence of post-traumatic stress. According to medical studies, a substantial proportion of impacted workers never return to their original job activity.

Faster fault clearance times, which are obtainable in most or all of the above cases, will reduce the likelihood of fatality and extent of thermal burns and long term impairment in these cases.

## 2.2 High voltage electrocution and thermal burns

Contrary to common belief, high voltage electric shock even by direct contact need not be fatal, and most shocks probably involve indirect contact which is even less likely to fatal. For example, a medical article [Electrical Injuries in Emergency Medicine Clinical Presentation] says: *"High-voltage AC injury with loss of consciousness and/or arrest: This is an unusual presentation of high-voltage AC injuries, which do not often cause loss of consciousness."* And *"Usually high-voltage injuries do not cause loss of consciousness but instead cause devastating thermal burns."*

There has been at least 1 fatality and 4 members of the public seriously injured as a result of indirect contact with the Endeavour Energy high voltage distribution network within in the last 20 years. These include:

| Date | Location | Circumstances |
|---|---|---|
| 24/02/2007 | Numbaa (North of Nowra) | A woman suffered third degree burns to her toes, loss of toe nails, and burns to her calf after receiving an indirect electric shock from her car, which was in contact with an 11kV power line. She was expected to be recovering in a hospital burns unit for a month |
| 30/04/2006 | Lake Tabourie (South of Ulladulla) | One boy received serious burn injuries and another received injuries to his right hand when the catamaran they were on contacted 11kV power lines above. |
| 28/12/1994 | Minnamurra River (North of Kiama) | A man was killed and a woman received severe burns and had her arm amputated when the mast of their catamaran came into contact with overhear HV lines. |

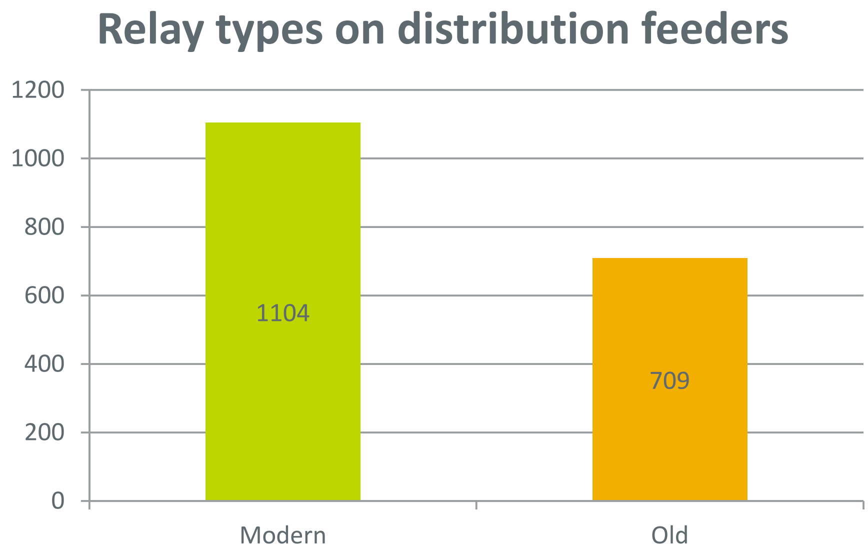
## 2.3 Modern technology and fault clearance

Compared to old electromechanical protection relays, the latest modern microprocessor protection relays improve the flexibility, accuracy and performance of the protection characteristic as well as adding additional functionality. Amongst other benefits, this allows the introduction of substantially faster electrical fault clearance times by taking advantage of:

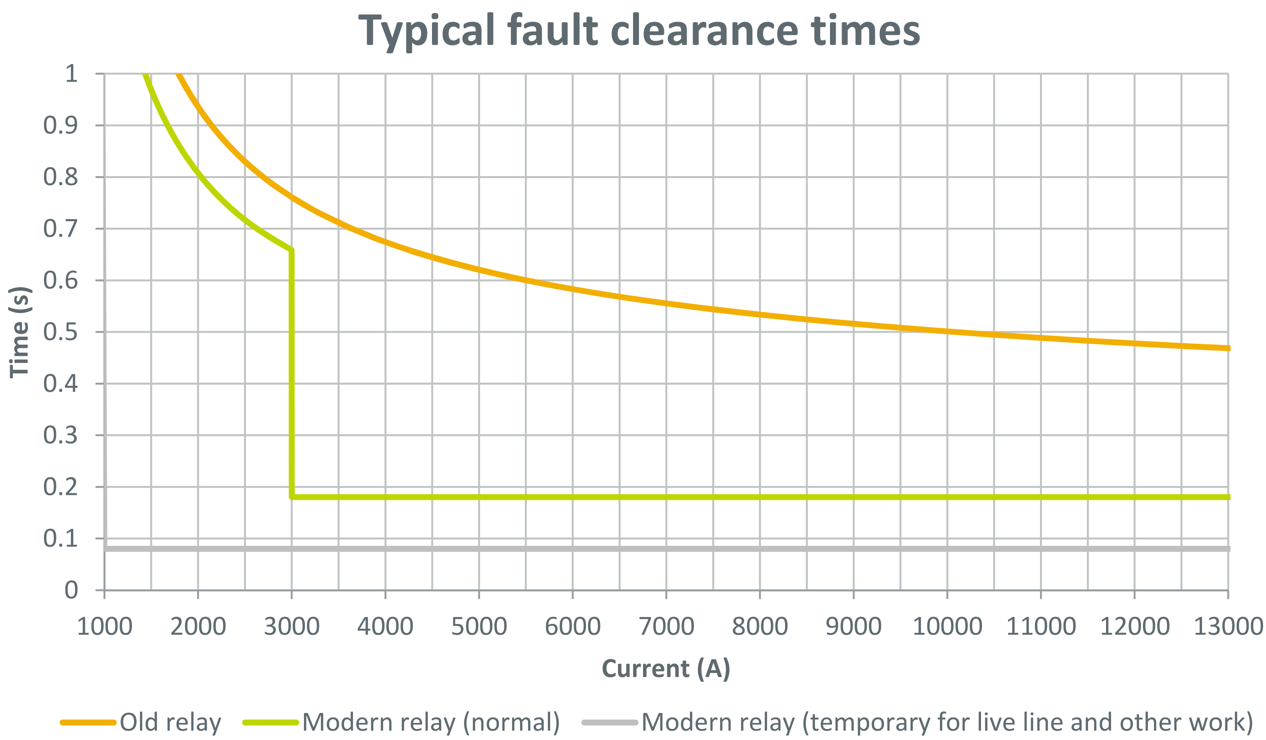
- multiple characteristic curve shapes;
- a more flexible time shift multiplier;
- a more accurate characteristic (e.g. trip, overshoot and reset times) resulting in the potential for a safe reduction in coordination margins, and most importantly;
- the ability to use high speed or instantaneous protection at higher fault levels, and the ability to change this characteristic by SCADA remote control depending on the circumstances (e.g. high risk works such as switching and live line work).

### 2.3.1 Protection operating times

There are currently 1813 distribution feeder protection systems. 1104 of these feeders currently have modern protection systems, and 709 do not. The old systems include relays such as CDG, PBO, ITP, and CO relays, and this program will see the replacement of these older systems, which are not otherwise being replaced through other projects, as well as a small number of older modern systems which are not capable of being modified to achieve the benefits of this program.



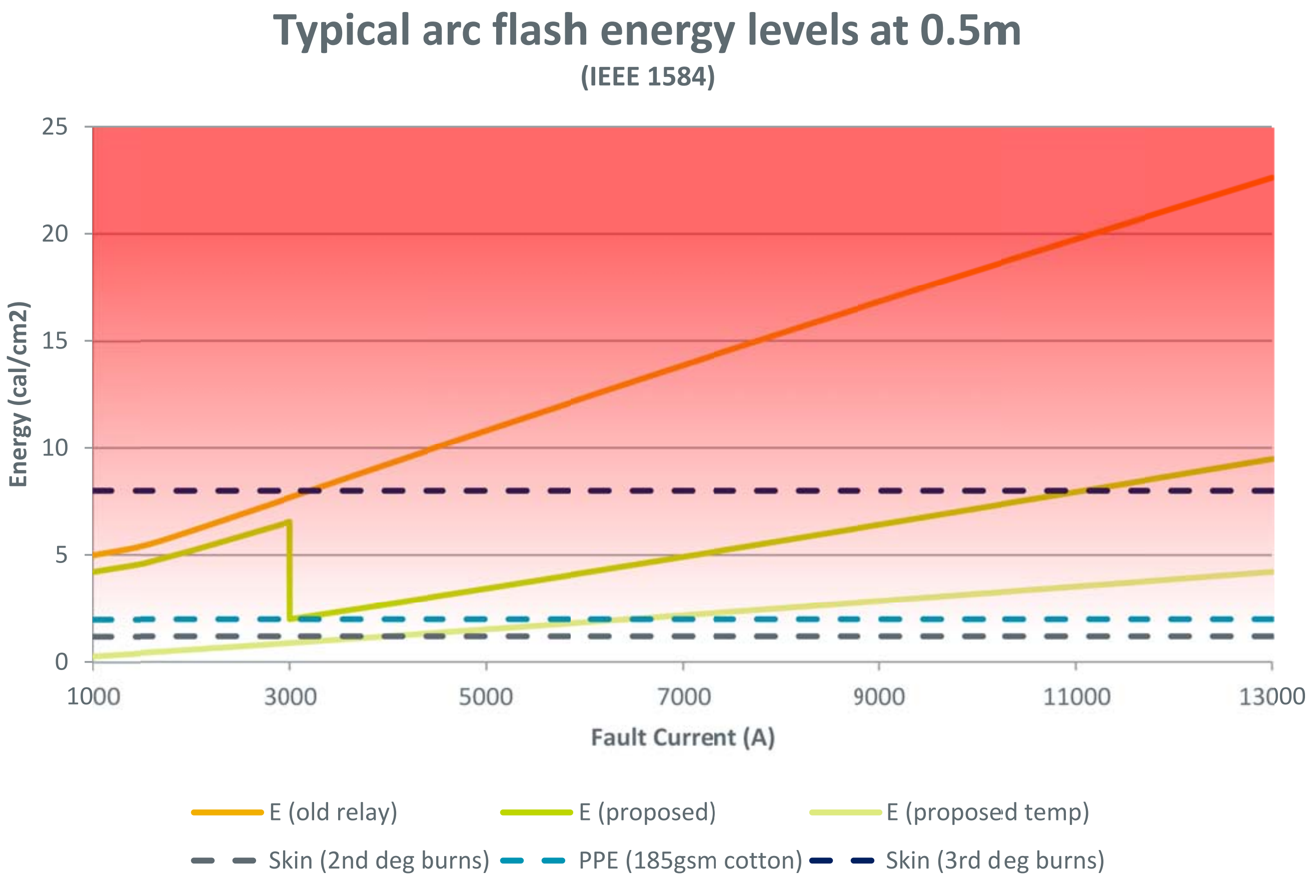

The graph below shows the substantial reduction in clearance time which can be achieved on a typical distribution feeder. Where the highset setting is included, the fault clearance time can typically be reduced by 60% to 85% for faults greater than 2-3kA. These higher fault levels, where the high-set is achievable correspond with our serious injury arc-flash accidents.



## 2.4 Fault Clearance time as a mitigation control

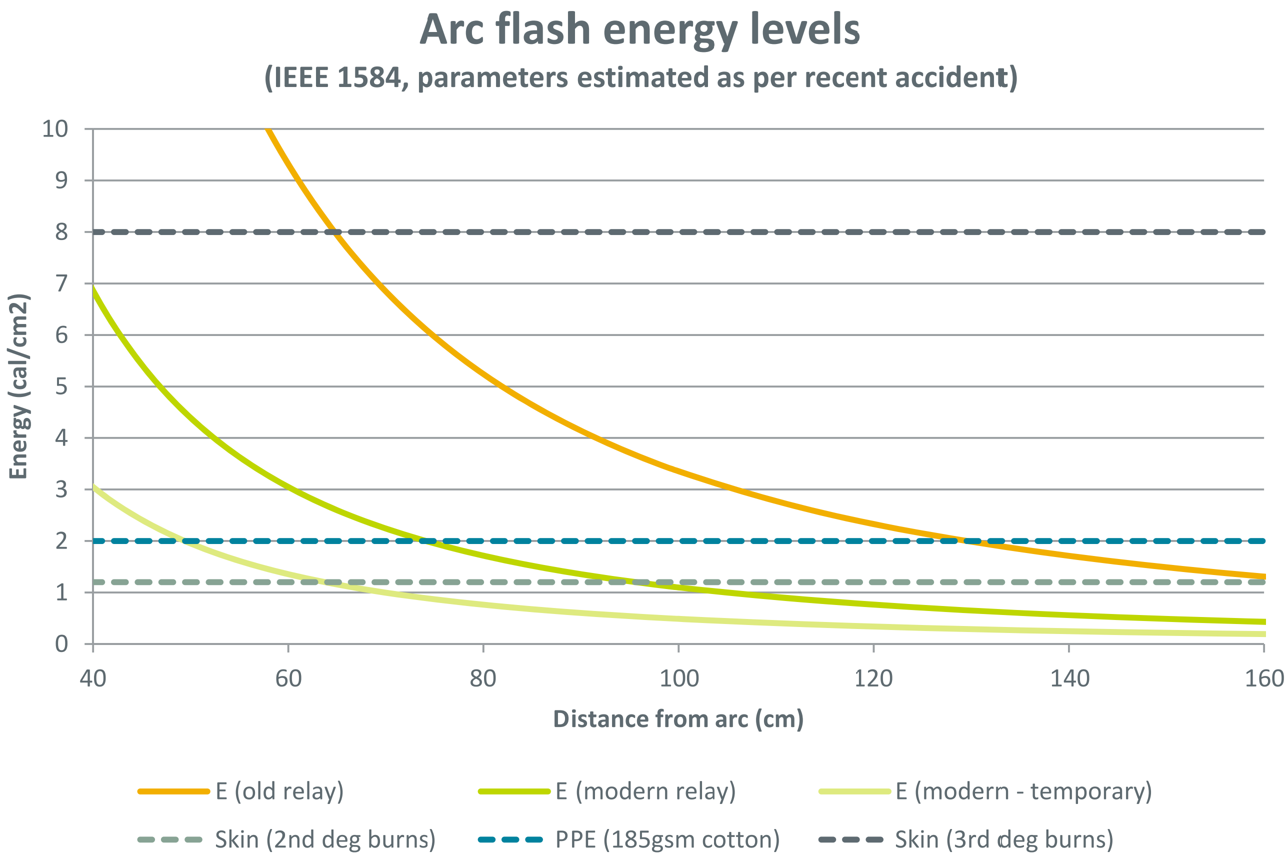
Fault clearance times are one of the key arc flash hazard controls listed in international best practice literature.

Experience and analysis shows that the majority of serious arc flash injuries are sustained at higher fault levels, say >3kA). It is at these higher fault levels where a substantial reduction in fault clearance times is normally available by way of a high-set (a higher speed fixed time protection element). The graph below illustrates the energy levels at 0.5m with and without a modern protection relay with typical ALARP settings. There is also a proposed temporary setting which is remotely controllable and results in very high speed clearance of electrical faults above 1kA. System operators can use this to reduce the risks to employees when work is being done, such as live line work, or switching high risk equipment.



## 2.5 Case analysis: One recent accident

The following graph is applicable to one recent accident which resulted in serious burn injuries to an Endeavour Energy District Operator. A witness to the accident estimated our employee to be between 1 and 2 meters away from the padmount substation when the arc flash occurred.




The orange line illustrates the arc incident energy that is estimated to have occurred on the day of the incident. The dark green line represents the typical energy levels if modern relays and typical minimum practical settings were employed, and the light green line represents the level of energy which could be employed on a temporary basis by SCADA remote control for high risk activities such as live line work, and the switching back onto possible faults, the latter being applicable to this event.

It is clear that at a distance of 1m, the energy levels are substantially reduced, and it is reasonable to conclude that it is likely that our Employee would not have sustained any significant injuries had the temporary settings been employed at the time of the accident if the person was at a distance greater than 1m, as witness reports have stated.

# 3.0 OTHER BENEFITS OF LOWER FAULT CLEARANCE TIMES

## 3.1 Bushfire risk

Bushfires can start as a result of high level faults caused by animals, wind (conductor clashing), and branches across lines etc. A faster fault clearance time will reduce the quantity of emitted particles from clashing, and will reduce the likelihood of the branch or animal remaining on fire when it drops to the ground, therefore reducing the risk of starting a bushfire.

## 3.2 Earthing risk, compliance & cost

### 3.2.1 Safety risk, compliance & cost savings

The amount of body current a person can tolerate before suffering ventricular fibrillation increases greatly with the exposure time. This is illustrated in the table below.

| Fault clearance time | Current required (50% probability of fibrillation) |
|---|---|
| 2.0s | 90mA |
| 1.5s | 100mA |
| 1.0s | 150mA |
| 0.5s | 350mA |
| 0.2s | 900mA |
| 0.1s | 1200mA |

Reducing fault clearance times from their existing levels (typically 0.5s to 1.0s at higher fault levels) to <0.2s substantially increases the current (and therefore step and touch voltage) required to cause ventricular fibrillation. This will see a reduction in step and touch potential risk and reduce costs associated with achieving compliance.

### 3.2.2 Developer costs

Developer earthing costs are estimated to reduce by $0.5 million per annum for a total of $11.5 million ($5.5M NPV) in avoided costs over the 20 year life of the new relays. This cost reduction is primarily due to simplified compliance criterion which increases the practicality of common earthing. There is also a reduction in political cost/risk by more frequently avoiding actions which are perceived to be slowing down urban development, for example, pool exclusion zones.

## 3.3 Cumulative damage to network plant

Reduced protection clearance times at high fault levels will result in a reduction of through fault energy which will reduce the cumulative thermal and mechanical wear/damage to equipment carrying the fault current. This is most relevant to zone substation transformers and conductors/cables. There is also cost saving potential.

### 3.3.1 Conductor fault ratings

Endeavour Energy has a large number of fault rating exceeded conductors in the network. One consequence of this is that when faults occur, mains can fall to the ground after a weak joint or annealed line breaks. This can result in a reliability impact and a safety hazard.

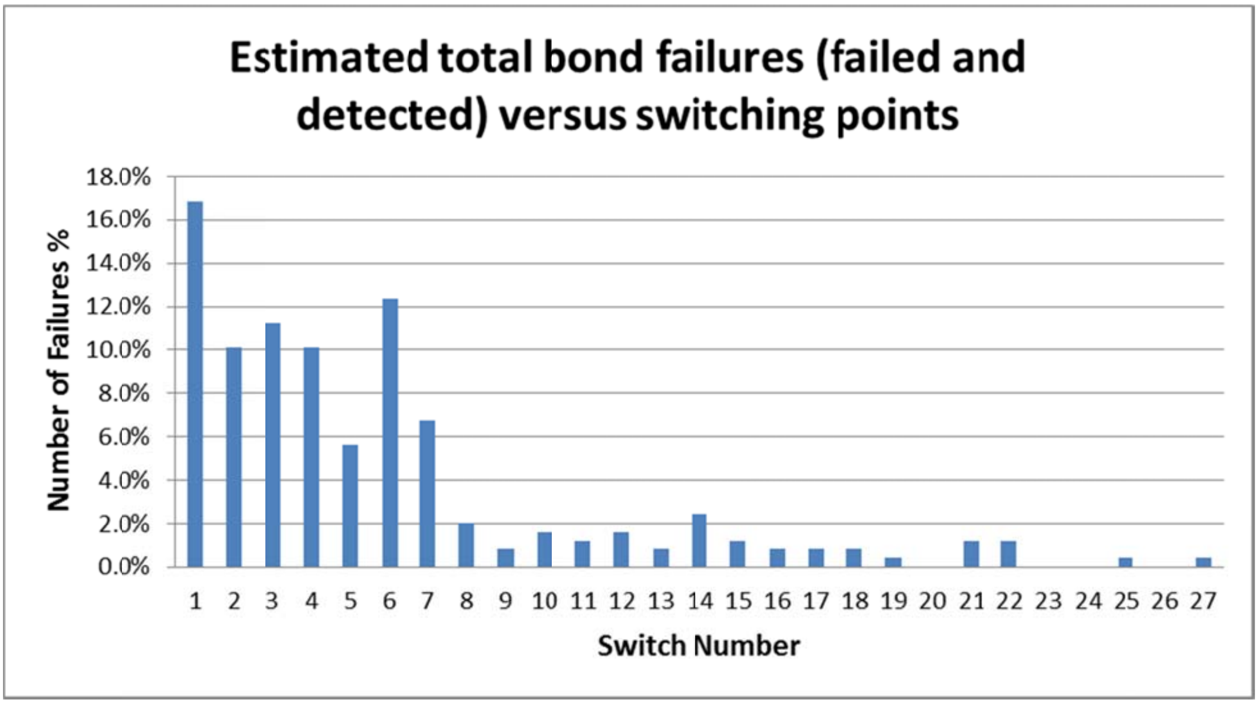
Some of these fault rating exceeded conductors can be adequately protected if modern relays are employed. It is estimated that $3.5 million worth of conductor replacements will be avoided through implementation of this program. Some of this cost saving has already been implemented by removal of work from the planned future Distribution Works Program.

### 3.3.2 Cumulative damage to network plant generally

Other sufficiently rated network plant will also benefit from a reduction in through fault energy. Some examples of through fault current impacts include:

- Approximately 10 years ago, both transformers at West Wollongong Zone Substation were destroyed as a result of repeated reclose attempts on a high level fault that was close to the substation on an 11kV feeder. This year, another transformer at West Wollongong failed after an external fault.
- A recent study by the Maintenance Engineering team indicates that over 10% of annual SAIDI (approximately 8 minutes per annum) is a result of overhead line or bond failures on the distribution network. The majority of distribution bond failures (resulting in lines on the ground, and loss of the feeder) occur close to the zone substation, where repeated exposure to high level fault current occurs.

Approximately 75% of bond failures occur within the first 7 switches (ABS or USL) from the zone substation. This correlates with high load and high and more frequent through fault current events.




This project will reduce cumulative thermal damage by typically 60% at high fault levels. This is likely to improve equipment life and should reduce the frequency of distribution feeder bond failures, thus improving the safety and reliability of the network.

## 3.4 Redundancy for reliability & compliance

Existing protection systems don't include full redundancy for relay failure or for circuit breaker failure. The impact of non-redundant relay failure or circuit breaker failure can include uncleared faults, with mains down at multiple locations and complete annealing of the backbone of the conductor and/or total loss of the zone substation load. This has occurred multiple times in the last decade, the most recent being out of Westmead zone substation for the cable theft incident at Northmead. In this case, the fault and circuit breaker failure resulted in a much longer clearance time and more extensive injuries to the arc flash victim as well as total loss of the zone substation. The fault energy also welded shut an air break switch which was unable to be opened to isolate the fault location, this being a relevant example to the cumulative network damage argument above.

### 3.4.1 Relay failure

The current Endeavour Energy standard (and industry practice generally) is to provide full redundancy for distribution feeder faults, and this project will see this implemented where older relays are employed.

### 3.4.2 Circuit breaker failure

This project will include the installation of CB failure which will reduce the likelihood of uncleared (or very slow to clear) faults, as well as reducing the extent of reliability impact. At these sites, the reliability impact normally results in a loss of the zone substation event. These incidents will instead result in the loss of a single busbar only. This typically reduces the reliability impact of a circuit breaker failure event by at least 50%.

For example, data from both SFR and OMS dating back to the year 2000 indicates that at Kingswood Zone Substation there have been 4 total loss of station load events due to circuit breaker failure. This program would likely have substantially reduced the consequence (extent of loss of load) in all 4 events.

| Incident Date | Reporting Comments | CMI | Customers Interrupted |
|---|---|---|---|
| 18/08/2001 10:51 | Fault On 11kv Feeder 9022 Slow Opening Of CB Caused Trip Of No 1 & No 2 Transformers - Loss Of Kingswood Zone Sub | 1443232 | 12045 |
| 1/12/2005 14:03 | 11kv Feeder CB 9032 Failed To Open Causing Number 1 And 2 Transformer To Trip Loss Of Kingswood ZS | 1141018 | 14132 |
| 13/07/2006 13:35 | Bird Across 11kv Pole 400 Cadden Rd Orchard Hills - 11kv CB 9032 Burnt Out Trip Coil - CB Failed To Trip - See Logs 200605689/91 - Loss Of Zone Sub | 736411 | 14266 |
| 1/11/2014 14:07 | Lockout of 33kV Transformer No 1 (O/C) and Lockout of 33kV Transformer No 2 at Kingwood ZS - Loss of Kingswood ZS - Feeders Patrolled - No Fault Found | 1884581 | 11962 |

**Circuit breaker failure related loss of station load (Kingswood ZS 2000 to 2014)**

In 2013, there were at least 2 x 11kV CB Failure events resulting in a total of 1.85 minutes of SAIDI. These occurred at Doonside ZS (March 2013) and Westmead ZS (October 2013). The Westmead event resulted in loss of supply to the hospital, and was coincidentally a result of an arc flash event which resulted in serious injuries to a member of the public. The protection clearance time, and arc flash energy was many magnitudes higher as a result of the circuit breaker failure.

It is expected that the SAIDI of most CB failure events will be reduced by at least 50% due to a lower number of bus sections interrupted, and due to faster restoration times due to clear information as to the nature of the failure.

Based on this information, it is estimated that the installation of CB Failure systems as a result of this project will result in a future average STPIS (Service Target Performance Incentive Scheme) cost benefit of $330k per annum (range $50k to $1M). Given that that cost to install CB Failure is $10k per site, or $700k (over this project), and this will be effective for 20 years, this appears to be justified on cost grounds alone.

## 3.5 Power quality & complaints

Improved protection clearance times improve the power quality for our customers. The reduction in dip time at high fault levels (from over 500ms to 180ms) will substantially reduce the likelihood of equipment restarts. This is particularly relevant to computer systems in residential and commercial areas, as well as to industrial customer processes.

For example, Endeavour Energy has received numerous complaints from major customers some of these regarding impacts as a result of faults on the distribution network. These impacts and the number of complaints will likely be reduced as a result of this program.

## 3.6 Information technology

Modern protection systems can send basic fault information to our SCADA systems and have detailed fault records which can be extracted manually.

### 3.6.1 Fault information and response

Immediate remote indication of fault type and fault current can enhance critical operational decisions. For example, knowledge of the fault level can assist in determining where on the network the fault is likely to be, and can potentially lead to faster restoration of load.

### 3.6.2 Condition based maintenance

Fault level data transmitted to SCADA presents some opportunities such as condition based CB maintenance. For example, maintenance could be scheduled based on actual wear and tear based on accurate knowledge of actual fault level and by knowing which phases were involved in each fault, rather than the existing practice which assumes maximum fault level and all three phases for each fault operation.

### 3.6.3 Forensic analysis of network incidents

Detailed fault records from protection relays can assist in the investigation of incidents, helping to permit a better understanding of events, which can lead to more appropriate choice of remedial actions and can help enhance safety and reliability in the future.

This information can also be critical to assisting in identifying the circumstances around high consequence events.

# 4.0 CORE BALANCE CT'S AND HIGH RESISTANCE FAULTS

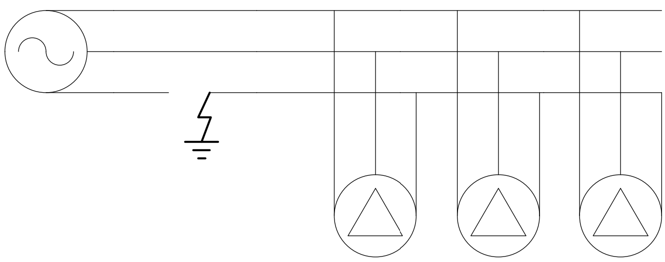
High voltage lines that remain energised on the ground carry with them a high risk of death or injury to individuals who make direct or indirect contact with the line. Both loss of life due to direct or indirect contact with a live downed conductor and loss of property due to fire have occurred on the Endeavour Energy network in the past. High resistance faults also appear to be the most common cause of network related fires.

This retrofit of protection systems offers the unique opportunity to install core balance CT's at minimal cost which will improve the likelihood of protection systems detecting these dangerous occurrences.

### 4.1.1 Case analysis

The following event occurred on the Endeavour Energy network a few years ago. Members of the public reported that lines were on the ground and witnesses saw arcing and smoking for 20 to 30 minutes before the fault was manually isolated from the supply. These types of events have a significant likelihood of fatal potential, and there is the precedence of a fatality via this means in the Endeavour Energy network.

In this case, as is not uncommon, the line remained energised only via the windings of downstream transformers. That is, it was not connected directly to the source, as is illustrated in the image below.



In these cases, even if fault resistance is low or zero, the fault current can be very low, and is primarily based on the impedance of the load connected to downstream transformers, as is illustrated by the technical analysis to follow.

Assuming no fault resistance, the effect of the fault on the 3 phase winding voltages of a delta-star Dyn11 transformer is shown in the figures below. The voltage across the two windings that are connected to the fault will drop and change in angle. On the secondary side, the voltages will also drop and change in angle. The phases are at reduced voltages and are no longer 120 degrees apart. Some load will trip out, some load (e.g. constant power devices such as switch mode power supplies) will draw more current, and purely resistive loads keep the same impedance drawing less current. Embedded generation such as solar panels is likely to trip out resulting in an apparent decrease in impedance.

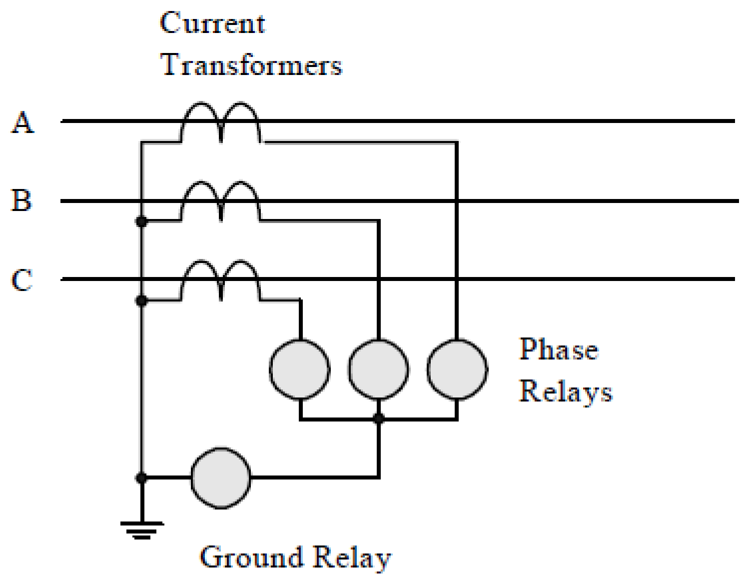
At the time of the incident, the estimated load current connected downstream of the fault was approximately 5A of primary current. Assuming no fault resistance and only constant impedance load, the calculated residual earth fault current in this case is 1.7A.

| | Pre-fault | | Post-fault | |
|---|---|---|---|---|
| | Magnitude | Angle | Magnitude | Angle |
| | | | | |
| **IA (line)** | 5.00A | 0° | 4.41A | -19° |
| **IB (line/fault)** | 5.00A | -120° | **1.67A** | **-120°** |
| **IC (line)** | 5.00A | 120° | 4.41A | 139° |

It can be seen that the residual current (earthfault current) in this case is 1.67A compared to a pre-fault load current of 5A. This assumes star connected constant impedance load with a power factor of unity and a fault resistance of zero. Whilst there are several overly-simplistic assumptions in this analysis, it remains conceptually correct. In many cases of lines down, the fault will remain connected only through the windings of downstream distribution transformers, and in these cases the maximum residual current will be proportional (33% if all loads are constant impedance) to the downstream connected load current, which will usually be very small. A 1A or lower SEF pickup will increase the likelihood of these types of faults, as well as normally fed high impedance faults being detected.

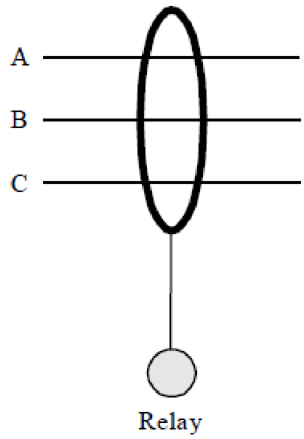
### 4.1.2 Residual current measurement

The current method of providing SEF (sensitive earthfault) protection is to use the 3 phase residual CT connection as shown in the figure below. The disadvantage of this scheme is that the SEF pickup setting has to be large enough to allow for CT imbalance due to the mismatch of CT errors. For example, if 3 phase CT's are carrying 300A of load current and their error is 1% (or 3A), the residual current measured could be several amps even when there is no real earth leakage current, hence the need to set the SEF pickup to say 4A, which due to errors, may not trip until there is up to 8A of residual current.




A core balance CT is a single CT which fits over the entire 3 phase cable to measure the earth leakage current. Earth leakage protections utilising a core balance CT can be set much more sensitive than a residual CT connection (or calculated residual current), because of lower and non-cumulative errors. Pickup sensitivity with a core balance CT will typically be 1A or lower, compared to 3A to 10A with a conventional CT residual connection.

The more sensitive setting will reduce the likelihood of lines remaining live on the ground. It is difficult to quantify the cost benefit in this case, but core balance CTs are qualitatively considered to be reasonably practical with a cost which is not grossly disproportionate to the benefit gained.



### 4.1.3 Installation of core balance CT's

It is possible to retrofit this scheme to existing installations by installing a split core CT around the distribution cable (the cable screens have to be brought back through the CT to avoid measuring any return current that returns via the cable sheath). This was done in a recent trial at Blackheath Zone Substation at a cost of approximately $4000 per feeder.

| Item | Cost | Remarks |
|---|---|---|
| Split core balance CT | $2,500 | $630ea |
| Cable tray and hardware | $2,000 | |
| Labour (sub tech) | $5,600 | (2 x 5 days) |
| Labour (protection tech) | $2,800 | (1 x 5 days) |
| Overheads | $2,100 | |
| **TOTAL** | **$15,000** | **$3,750 per feeder** |

**Cost of installation of core balance at Blackheath ZS**

**Core balance CT's installed at Blackheath Zone Substation**

A core balance CT installed at Blackheath Zone Substation

# 5.0 RISKS

## 5.1 Reliability impacts

Both the SEF sensitivity increase and the high-set may result in reliability impacts on the distribution network.

### 5.1.1 SEF sensitivity

Ten years ago, most of Endeavour Energy's North and Central region distribution feeders had an SEF pickup setting of 8A or 10A, and many Southern region sites did not have dedicated SEF protection at all. Around 5 years ago, a program commenced to change the settings on all SEF relays to around 4A, and this is now in place on most distribution feeders. This project proposes a sensitivity increase to 1A through the use of core balance CT's.

A trial of core balance CT's with a 1A pickup setting has been undertaken on all 4 feeders at Blackheath Zone Substation. This has been in place since October 2013 (1.5 years). There has been one incident at Blackheath Zone Substation where a broken bond on the distribution feeder (open circuit on one phase) has caused the 1A SEF to operate. Analysis indicates that unbalanced line capacitive currents are the likely cause of sufficient residual current in the case of the open circuited line, and the 1A setting is much more likely to operate for these types of open circuit faults.

Arguably, it may be desirable for this to occur, because open circuits are indicative of a network fault, and could involve conductors on the ground or in contact with a tree or pole creating a dangerous local touch voltage and the potential to start a fire. There will however be some instances of insulator or surge arrestor leakage or similar which cannot easily be located. System operations do have the capability to turn the SEF function off if required, and the SEF pickup can always be fully or partially reversed if the settings are overly problematic.

### 5.1.2 High-sets

High sets have been steadily introduced over the last 18 months on the distribution network, and as of mid-2015, over 5% of distribution feeders now have this function enabled. There have been no reported impacts so far. It is possible however that an occasional improper coordination for some rare distribution substation faults may occur which could result in an unwanted feeder outage. It is estimated that this might occur around once per annum, and result in a reliability impact worth around $50,000. Countering this risk is the fact that higher speed protection at high fault levels reduces the likelihood of bond failures during network faults which could result in an appreciable reliability improvement.

### 5.1.3 Conclusions

Without going ahead with the installations, it will be difficult to know the extent of reliability impact (which could be either benefit or disadvantage) as a result of this program. It is anticipated that if it be a disadvantage, that it would be relatively minor. If at any time the reliability impact exceeds expectations, a re-review of the program will be undertaken in light of the findings, and both the SEF sensitivity increase and/or high-set functionality can be fully or partially reversed.

# 6.0 OPTION COMPARISON

## 6.1 Option 1 (complete panel replacement)

This option involves the complete replacement of protection panels including two new protection relays per feeder. A core balance CT will also be installed where the feeder can feed overhead network. The key benefit of this option is minimisation of outage times and that old electromechanical relays, and associated panel wiring and links will be completely renewed. These benefits however are not considered to justify the difference in cost and will delay implementation unnecessarily.

| Summary – Option 1 | |
|---|---|
| Cost | $26.3 million (+$1.7 million contingency) |
| Description | Full panel replacement including two new relays. |
| Key points | • Replacement of all existing aged panel, relays, wiring etc.<br>• Highest cost option<br>• Slowest to complete – delays benefits (assuming fixed spend per annum)<br>• Minimises outage time<br>• Includes a one off allowance of $100k for secondary system branch technology development work to accommodate the changes. |
| **Not recommended** | |

## 6.2 Option 2a (retrofit one additional relay)

This option involves the retrofit of existing panels, where possible (where space and existing equipment condition permits). Under this option, only a single additional relay will be installed and the SEF relay can be removed, and the old electromechanical relays, and associated panel wiring and links will be retained. A core balance CT will also be installed where the feeder can feed overhead network. The key benefit of this option is that it is cheaper, and faster to implement than option **1**.

| Summary – Option 2a | |
|---|---|
| Cost | $16.9 million (+$1.5 million contingency) |
| Description | Retrofit 1 x additional relay onto the existing panel (a small proportion of sites will require full panel replacement including two new relays.) |
| Key points | • Leaves old aged panel, relays and wiring in place<br>• Lowest cost option<br>• Fastest to implement<br>• Includes a one off allowance of $100k for secondary system branch technology development work to accommodate the changes. |
| **Not recommended** | |

## 6.3 Option 2b (retrofit one additional relay – future strategy)

This option is the same as option 2a, in that a single protection relay will be retrofitted into the panel; however the relay and communication systems will be upgraded to conform to the anticipated new feeder standard. The relay will include voltage measurement, more detailed fault recording capability, and the communications system will be upgraded to more capable Ethernet. This functionality has the potential to result in a significant STPIS return, and better prepares us for challenges and control decisions relating to future networks.

This option represents an increase to the cost of PS012 of 17% or $2.8 million over option 2a.

### 6.3.1 Reliability improvement

One important feature of the additional functionality will be distance to fault measurement. If this works well, it will assist system operations in the identification of the fault location and will therefore reduce restoration times. It is difficult to know the degree of the benefit; however an assessment based on the following assumptions yields a potential total saving of $3.2 million over the next 10 years. This has allowed for the progressive project implementation and re-benchmarked targets after the first 5 years.

The value of customer reliability over the entire 20 year life of the relay has been calculated to be $17.3 million NPV using a discount rate of 5.88%.

| Parameter | Value |
|---|---|
| Data | 3 years of outage data between 2012 and 2015 |
| Filters/assumptions | • Outages on underground feeders only<br>• Outages over 60 minutes in duration were reduced to a limit of 60 minutes |
| **STPIS (Total NPV value)** | **$3.2 million** |
| **Value of Customer Reliability (NPV over 20 years)** | **$17.3 million** |

### 6.3.2 Future network readiness

The voltage measurement function and Ethernet communications will allow for the real time measurement of real and reactive power flows, and power factor at an individual distribution feeder level. It is anticipated that this information will be required in the future in order to manage the network and make network investment decisions when we are faced with high levels of embedded generation penetration. This is already starting to be realised, with one feeder out of Doonside Zone Substation having reverse power flow on mild sunny days.

The cost of retrofitting relays with the above capability after this program has been implemented is estimated to cost no less than 50% of the cost of this project. If this were to be required in 5 years, the cost would be $7.2 million NPV. It is therefore prudent to invest in this capability now rather than risk the need to prematurely replace these devices in the future.

This option aligns the renewal with the Networks NSW Future Networks Strategy, particularly the following objectives:

*“The NSW DNSPs will invest in advanced distribution network management (monitoring and control) functionality over time to deliver efficient network operations and performance as emerging technologies are increasingly interfaced to the network.”*

*“Invest prudently in distributed network monitoring capability that provides relevant network information and facilitates more informed investment decisions and efficient network automation.”*

### 6.3.3 Advanced & remotely accessible fault data recording

Our current main distribution feeder relays have limited fault recording capabilities and the recordings have to be downloaded manually from the substation sites. Fault recordings assist greatly in the forensic analysis of network related events such as safety incidents, bushfires, and protection maloperations, often providing the information necessary to make remedial actions and sound risk control decisions.

There are many examples of where fault recordings were inaccessible or unhelpful because either they were overwritten by subsequent faults prior to the attempts to access these records, or there was insufficient/partial information in the fault recording due the relay limitations. This prevents robust analysis of the fault, and in certain cases could deny Endeavour Energy the information required to determine if our assets were or were not the cause of a high consequence incident.

The proposed solution will see protection systems installed with 5 times the fault recording duration capability, remotely accessible fault recordings through Ethernet communications, more available data - including voltage waveforms, and dedicated channel for sensitive earth fault recording.

### 6.3.4 Technology development allowance

This option includes a one off up front allowance of $300k (approx. 1.5FTE) to allow for the development of the technology solutions required to realise the benefits listed above. This will be allocated to Secondary Systems Branch in the Engineering division in 2015-16.

### 6.3.5 Conclusion

The cost of this option is $2.8 million which is an incremental cost of 17% over the base option 2a. Based on the information/assessment above, the value of this option is considered to be worth in excess of the cost and is therefore recommended.

| Summary – Option 2b | |
|---|---|
| Cost | $19.7 million (+$1.7 million contingency) |
| Description | Retrofit 1 x additional relay onto the existing panel (a small proportion of sites will require full panel replacement including two new relays). Relays will be capable of VT measurement, have Ethernet communications, and more fault recording capability. |
| Key points | • Adds remote distance to fault capability to reduce outage times.<br>• Aligns with NNSW strategy, provides power flow information on distribution feeders to assist with future network management.<br>• Adds robust fault recording capability critical to the analysis of incidents.<br>• Includes a one off allowance of $300k (approx. 1.5FTE) for secondary system branch technology development work to accommodate the changes. |
| Recommended | |

## 7.0 RECOMMENDATIONS

It is recommended that a business case be developed for the approval to spend $7.0 million across the 2015/16 and 2016/17 financial years. This will see these works applied to replace 241 distribution feeder protection systems across 26 sites. In summary, the upgrade consists of:

- Implement modern feeder protection systems and as per future networks strategy standard with voltage measurement and Ethernet communications capability, including the necessary SCADA system upgrades required to accommodate the installation.
- Retrofit the core balance CT's on feeders which can potentially feed overhead network in order to increase the potential sensitivity of protection systems to lines on the ground from approximately 4A to 1A.
- Install circuit breaker failure systems to improve safety, compliance and reliability.

**Prepared by**

14/05/15

Matthew Browne
Protection Manager

**Endorsed by:**

Stephen Lette
Manager Secondary Systems

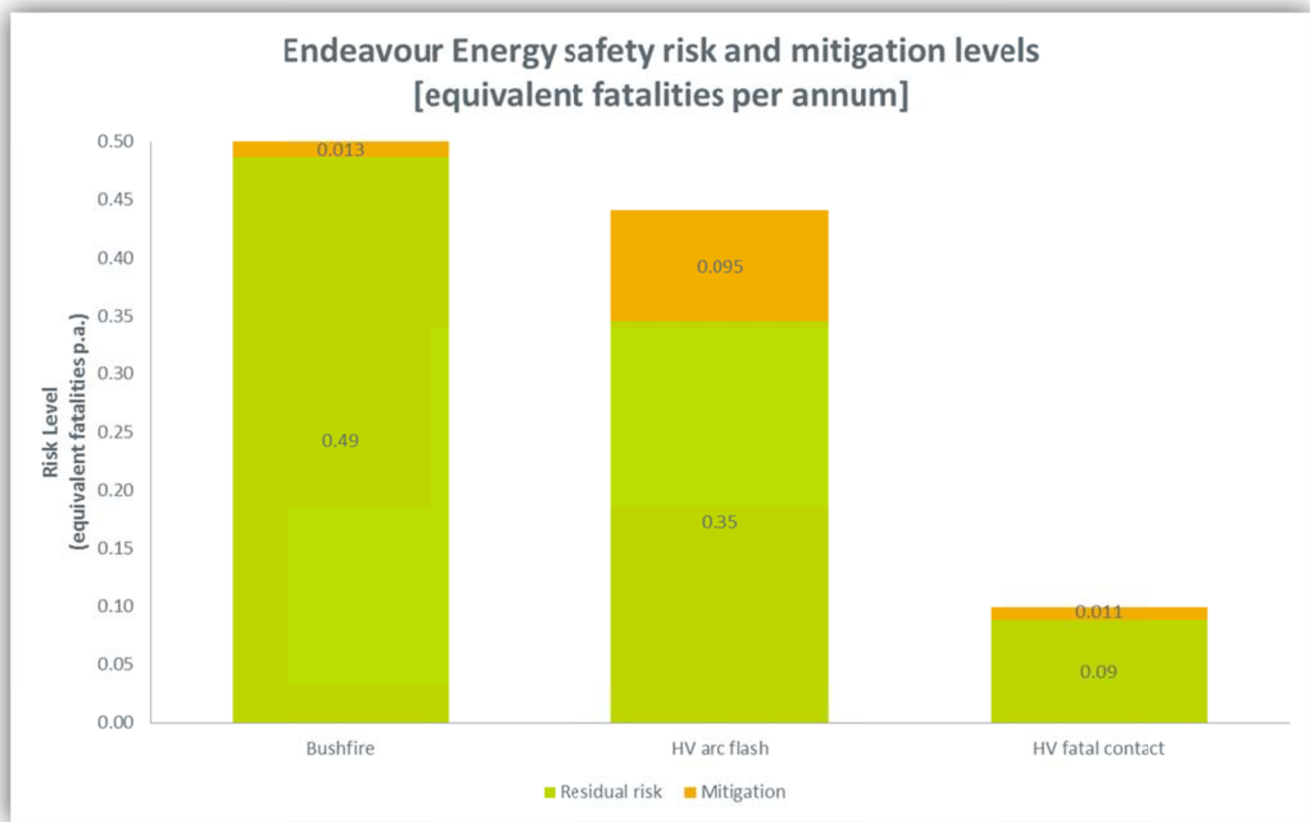
# 8.0 APPENDIX A (PRELIMINARY SITE LIST)

Ignoring incapable relays which will be replaced under alternative SAMP and SARP projects, there are 623 protection relays across 66 zone substations which require replacement under this project.

## 8.1 Cost benefit prioritisation

Substations have been prioritised based on a quantitative assessment of the safety benefits per site, divided by the total site cost. In this way, for a fixed time-spend, the most safety benefit is gained in the shortest time possible.

The benefits considered and their magnitudes are listed in the table below. These values are based on the quantitative safety benefits calculated in the appendix, but over a consistent 20 year period, with disproportion factor of 10, and without net present value. Net present value has not been used because this would distort the prioritisation in favour of long term gains which are irrelevant when considering implementation priority.




| Risk category | Total risk EE [eq. fatalities p.a.] | Residual risk [eq. fatalities p.a.] | Mitigation [eq. fatalities p.a.] | Feeder distance [km] | Value [$/km] |
|---|---|---|---|---|---|
| Bushfire | 0.5 | 0.49 | 0.013 | 947 | $11,840 |
| Arc flash | 0.441 | 0.35 | 0.095 | 1928 | $43,850 |
| Fatal contact | 0.1 | 0.09 | 0.011 | 2422 | $3,969 |

### 8.1.1 Assumptions

In order to conduct the cost benefit assessment, the following assumptions were used:

- Arc flash risk only pertains to underground network and is the same at all substations on a per km basis.
- The fatal contact risk only applies to overhead networks and is the same for all overhead feeders on a pre km basis.
- The bushfire risk benefit has been applied exclusively to 20 substations which are considered to present a high risk of bushfire. The risk mitigation is considered to be the same at all locations on a per km basis.
- Zones with overhead networks >50km have been reduced to 50km to represent the network which is effected by the zone circuit breaker (i.e. not covered separately by a recloser or fuse).

## 8.2 Site priority list and suggested timing

| Substation | Fdrs | Region | UG (km) | OH (km) (fdr CB) | PS009 | High bushfire | Value 20yrs (arc flash) | Value 20yrs (fatal contact) | Value 20yrs (bushfire) | Value 20yrs (total) | Site Cost | Cost benefit ratio | Priority | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Quakers Hill** | 7 | North | 81.13 | 21.75 | | | $ 3,557,653 | $ 86,319 | $ - | $ 3,643,973 | $ 187,250 | 19.5 | 1 | 2015 |
| **Quarries** | 10 | Central | 94.15 | 25.50 | | | $ 4,128,495 | $ 101,191 | $ - | $ 4,229,686 | $ 262,870 | 16.1 | 2 | 2015 |
| **Culburra** | 2 | South | 5.54 | 50.00 | | Yes | $ 242,974 | $ 198,444 | $ 592,009 | $ 1,033,427 | $ 79,550 | 13.0 | 3 | 2015 |
| **Minto** | 19 | Central | 125.66 | 33.39 | Yes | | $ 5,510,039 | $ 132,501 | $ - | $ 5,642,540 | $ 442,790 | 12.7 | 4 | 2015 |
| **Bonnyrigg** | 13 | Central | 84.39 | 28.20 | | | $ 3,700,386 | $ 111,915 | $ - | $ 3,812,300 | $ 327,490 | 11.6 | 5 | 2015 |
| **Albion Park** | 5 | South | 39.95 | 50.00 | | | $ 1,751,771 | $ 198,444 | $ - | $ 1,950,215 | $ 193,150 | 10.1 | 6 | 2015 |
| **Kellyville** | 6 | North | 35.31 | 20.28 | | | $ 1,548,219 | $ 80,485 | $ - | $ 1,628,704 | $ 165,710 | 9.8 | 7 | 2015 |
| **Cranebrook** | 10 | North | 52.24 | 50.00 | | | $ 2,290,646 | $ 198,444 | $ - | $ 2,489,090 | $ 262,870 | 9.5 | 8 | 2015 |
| **Mittagong** | 5 | Central | 12.43 | 50.00 | Yes | Yes | $ 545,189 | $ 198,444 | $ 592,009 | $ 1,335,643 | $ 144,170 | 9.3 | 9 | 2015 |
| **Ambarvale** | 9 | Central | 60.26 | 44.69 | | | $ 2,642,368 | $ 177,362 | $ - | $ 2,819,730 | $ 328,430 | 8.6 | 10 | 2015 |
| **Emu Plains** | 9 | North | 28.21 | 50.00 | | Yes | $ 1,237,101 | $ 198,444 | $ 592,009 | $ 2,027,555 | $ 241,330 | 8.4 | 11 | 2015 |
| **Prestons** | 12 | Central | 53.71 | 37.95 | | | $ 2,355,281 | $ 150,635 | $ - | $ 2,505,916 | $ 298,950 | 8.4 | 12 | 2015 |
| **Homepride** | 9 | Central | 39.82 | 21.46 | | | $ 1,745,895 | $ 85,168 | $ - | $ 1,831,064 | $ 219,790 | 8.3 | 13 | 2015 |
| **Huskisson** | 5 | South | 8.89 | 50.00 | | Yes | $ 389,916 | $ 198,444 | $ 592,009 | $ 1,180,369 | $ 144,170 | 8.2 | 14 | 2015 |
| **Kurrajong** | 4 | North | 4.85 | 50.00 | | Yes | $ 212,849 | $ 198,444 | $ 592,009 | $ 1,003,302 | $ 122,630 | 8.2 | 15 | 2016 |
| **Glenmore Park** | 9 | North | 64.72 | 19.24 | | | $ 2,838,159 | $ 76,377 | $ - | $ 2,914,537 | $ 366,400 | 8.0 | 16 | 2016 |
| **Wisemans** | 4 | North | 2.94 | 50.00 | Yes | Yes | $ 129,007 | $ 198,444 | $ 592,009 | $ 919,461 | $ 125,700 | 7.3 | 17 | 2016 |
| **Arndell Park** | 10 | North | 41.64 | 24.93 | | | $ 1,826,097 | $ 98,932 | $ - | $ 1,925,030 | $ 269,460 | 7.1 | 18 | 2016 |
| **Blackmans Flat** | 6 | North | 9.44 | 50.00 | | Yes | $ 414,077 | $ 198,444 | $ 592,009 | $ 1,204,531 | $ 169,860 | 7.1 | 19 | 2016 |
| **North Parramatta** | 10 | Central | 39.87 | 22.30 | | | $ 1,748,307 | $ 88,490 | $ - | $ 1,836,797 | $ 259,920 | 7.1 | 20 | 2016 |
| **Kentlyn** | 14 | Central | 38.63 | 47.11 | | Yes | $ 1,693,757 | $ 186,990 | $ 557,838 | $ 2,438,586 | $ 357,780 | 6.8 | 21 | 2016 |
| **West Pennant Hills** | 12 | North | 47.47 | 8.77 | Yes | | $ 2,081,656 | $ 34,807 | $ - | $ 2,116,463 | $ 313,620 | 6.7 | 22 | 2016 |
| **Rooty Hill** | 13 | North | 66.96 | 41.54 | Yes | | $ 2,936,384 | $ 164,868 | $ - | $ 3,101,251 | $ 463,940 | 6.7 | 23 | 2016 |
| **North Richmond** | 8 | North | 16.23 | 50.00 | | Yes | $ 711,645 | $ 198,444 | $ 592,009 | $ 1,502,098 | $ 225,300 | 6.7 | 24 | 2016 |
| **Bow Bowing** | 20 | Central | 68.29 | 50.00 | | | $ 2,994,354 | $ 198,444 | $ - | $ 3,192,798 | $ 490,260 | 6.5 | 25 | 2016 |
| **Anzac Village** | 10 | Central | 35.65 | 25.43 | | | $ 1,563,435 | $ 100,933 | $ - | $ 1,664,367 | $ 269,460 | 6.2 | 26 | 2016 |
| **Bossley Park** | 10 | Central | 58.42 | 4.69 | | | $ 2,561,640 | $ 18,606 | $ - | $ 2,580,246 | $ 427,470 | 6.0 | 27 | 2017 |

| Substation | Fdrs | Region | UG (km) | OH (km) (fdr CB) | PS009 | High bushfire | Value 20yrs (arc flash) | Value 20yrs (fatal contact) | Value 20yrs (bushfire) | Value 20yrs (total) | Site Cost | Cost benefit ratio | Priority | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Kingswood** | 13 | North | 40.22 | 50.00 | | | $ 1,763,698 | $ 198,444 | $ - | $ 1,962,143 | $ 335,700 | 5.8 | 28 | 2017 |
| **Kenthurst** | 8 | North | 11.75 | 50.00 | | Yes | $ 515,020 | $ 198,444 | $ 592,009 | $ 1,305,474 | $ 225,300 | 5.8 | 29 | 2017 |
| **Wentworth Falls** | 4 | North | 3.51 | 50.00 | Yes | Yes | $ 153,783 | $ 198,444 | $ 592,009 | $ 944,236 | $ 170,270 | 5.5 | 30 | 2017 |
| **Bringelly** | 3 | Central | 8.38 | 50.00 | | | $ 367,465 | $ 198,444 | $ - | $ 565,909 | $ 103,620 | 5.5 | 31 | 2017 |
| **Plumpton** | 14 | North | 40.48 | 48.17 | Yes | | $ 1,774,968 | $ 191,165 | $ - | $ 1,966,133 | $ 366,690 | 5.4 | 32 | 2017 |
| **Appin** | 4 | Central | 2.59 | 50.00 | | Yes | $ 113,484 | $ 198,444 | $ 592,009 | $ 903,938 | $ 170,270 | 5.3 | 33 | 2017 |
| **Hazelbrook** | 11 | North | 12.00 | 50.00 | | Yes | $ 526,378 | $ 198,444 | $ 592,009 | $ 1,316,831 | $ 253,540 | 5.2 | 34 | 2017 |
| **Cambridge Park** | 9 | North | 28.33 | 6.38 | | | $ 1,242,057 | $ 25,302 | $ - | $ 1,267,358 | $ 253,540 | 5.0 | 35 | 2017 |
| **Portland** | 4 | North | 0.98 | 50.00 | | Yes | $ 43,061 | $ 198,444 | $ 592,009 | $ 833,514 | $ 170,270 | 4.9 | 36 | 2017 |
| **Macquarie Fields** | 13 | Central | 49.97 | 29.79 | Yes | | $ 2,191,369 | $ 118,217 | $ - | $ 2,309,586 | $ 475,590 | 4.9 | 37 | 2017 |
| **Dundas** | 13 | North | 33.03 | 50.00 | | | $ 1,448,547 | $ 198,444 | $ - | $ 1,646,991 | $ 344,060 | 4.8 | 38 | 2017 |
| **Moss Vale** | 7 | Central | 16.63 | 50.00 | Yes | | $ 729,404 | $ 198,444 | $ - | $ 927,848 | $ 196,730 | 4.7 | 39 | 2017 |
| **Cattai** | 8 | North | 6.31 | 50.00 | | Yes | $ 276,826 | $ 198,444 | $ 592,009 | $ 1,067,280 | $ 230,910 | 4.6 | 40 | 2017 |
| **Port Central** | 5 | South | 12.11 | 27.78 | | | $ 530,938 | $ 110,272 | $ - | $ 641,210 | $ 151,470 | 4.2 | 41 | 2018 |
| **Lithgow** | 12 | North | 24.03 | 50.00 | | Yes | $ 1,053,545 | $ 198,444 | $ 592,009 | $ 1,843,998 | $ 442,950 | 4.2 | 42 | 2018 |
| **Katoomba** | 10 | North | 16.08 | 50.00 | | Yes | $ 705,199 | $ 198,444 | $ 592,009 | $ 1,495,652 | $ 366,490 | 4.1 | 43 | 2018 |
| **West Castle Hill** | 22 | North | 65.21 | 17.17 | Yes | | $ 2,859,251 | $ 68,146 | $ - | $ 2,927,397 | $ 736,690 | 4.0 | 44 | 2018 |
| **Seven Hills** | 12 | North | 24.28 | 40.84 | Yes | | $ 1,064,639 | $ 162,069 | $ - | $ 1,226,708 | $ 321,430 | 3.8 | 45 | 2018 |
| **Riverstone** | 8 | North | 15.46 | 50.00 | Yes | | $ 677,748 | $ 198,444 | $ - | $ 876,193 | $ 230,910 | 3.8 | 46 | 2018 |
| **Glossodia** | 6 | North | 1.99 | 50.00 | | Yes | $ 87,130 | $ 198,444 | $ 592,009 | $ 877,584 | $ 241,410 | 3.6 | 47 | 2018 |
| **Horsley Park** | 9 | Central | 16.36 | 50.00 | | | $ 717,170 | $ 198,444 | $ - | $ 915,614 | $ 253,540 | 3.6 | 48 | 2018 |
| **Liverpool** | 12 | Central | 33.29 | 36.99 | | | $ 1,459,773 | $ 146,821 | $ - | $ 1,606,594 | $ 453,960 | 3.5 | 49 | 2018 |
| **Warilla** | 6 | South | 13.30 | 50.00 | | | $ 583,207 | $ 198,444 | $ - | $ 781,652 | $ 232,300 | 3.4 | 50 | 2018 |
| **Luddenham** | 4 | North | 4.68 | 50.00 | | | $ 205,043 | $ 198,444 | $ - | $ 403,488 | $ 132,070 | 3.1 | 51 | 2018 |
| **Blaxland** | 11 | North | 11.16 | 50.00 | | Yes | $ 489,543 | $ 198,444 | $ 592,009 | $ 1,279,997 | $ 420,510 | 3.0 | 52 | 2019 |
| **Newton** | 10 | North | 23.14 | 21.49 | | | $ 1,014,781 | $ 85,287 | $ - | $ 1,100,068 | $ 387,060 | 2.8 | 53 | 2019 |
| **Sherwood** | 13 | Central | 18.39 | 48.35 | Yes | | $ 806,449 | $ 191,900 | $ - | $ 998,348 | $ 352,720 | 2.8 | 54 | 2019 |
| **North Wollongong** | 7 | South | 15.29 | 21.96 | | | $ 670,250 | $ 87,149 | $ - | $ 757,399 | $ 268,940 | 2.8 | 55 | 2019 |
| **Prospect** | 13 | North | 17.63 | 50.00 | Yes | | $ 773,035 | $ 198,444 | $ - | $ 971,479 | $ 352,720 | 2.8 | 56 | 2019 |
| **Lennox** | 14 | Central | 22.68 | 10.16 | | | $ 994,391 | $ 40,336 | $ - | $ 1,034,726 | $ 375,920 | 2.8 | 57 | 2019 |
| **North Rocks** | 9 | North | 13.36 | 31.71 | | | $ 585,838 | $ 125,845 | $ - | $ 711,684 | $ 259,920 | 2.7 | 58 | 2019 |

| Substation | Fdrs | Region | UG (km) | OH (km) (fdr CB) | PS009 | High bushfire | Value 20yrs (arc flash) | Value 20yrs (fatal contact) | Value 20yrs (bushfire) | Value 20yrs (total) | Site Cost | Cost benefit ratio | Priority | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cabramatta** | 13 | Central | 18.45 | 32.25 | | | $ 809,036 | $ 127,989 | $ - | $ 937,025 | $ 352,720 | 2.7 | 59 | 2019 |
| **Moorebank** | 11 | Central | 27.16 | 42.58 | Yes | | $ 1,191,015 | $ 169,007 | $ - | $ 1,360,022 | $ 582,550 | 2.3 | 60 | 2019 |
| **Carramar** | 9 | Central | 16.58 | 17.35 | | | $ 726,905 | $ 68,868 | $ - | $ 795,773 | $ 353,610 | 2.3 | 61 | 2019 |
| **Kenny Street** | 8 | South | 12.13 | 2.31 | | | $ 532,034 | $ 9,156 | $ - | $ 541,191 | $ 332,600 | 1.6 | 62 | 2020 |
| **Woodpark** | 8 | Central | 13.39 | 12.11 | Yes | | $ 587,022 | $ 48,051 | $ - | $ 635,074 | $ 391,980 | 1.6 | 63 | 2020 |
| **Inner Harbour** | 10 | South | 13.57 | 0.44 | | | $ 595,222 | $ 1,750 | $ - | $ 596,973 | $ 396,770 | 1.5 | 64 | 2020 |
| **Greystanes** | 13 | North | 7.02 | 46.80 | | | $ 307,960 | $ 185,760 | $ - | $ 493,720 | $ 361,530 | 1.4 | 65 | 2020 |
| **Berrima Junction** | 5 | Central | 0.45 | 0.00 | | Yes | $ 19,513 | $ - | $ - | $ 19,513 | $ 87,810 | 0.2 | 66 | 2020 |

# 9.0 APPENDIX B (BASIS FOR ARC FLASH CALCULATIONS)

The internationally recognised standards on Arc Flash are the American standards IEEE 1187 (calculations) and NFPA 70E (application and PPE). These standards are widely used in Australia and have been used as the basis for the calculations within this report.

The relevant Australian code of practice (ENA NENS 09 – Guideline for the Selection, Use and Maintenance of Personal Protective Equipment for Electrical Hazards) which specifies a methodology for arc flash calculations and PPE requirements has received serious criticism and has not received general acceptance. This standard has not been used.

For example, comments regarding the Australian code of practice NENS 09 from 'Arc Flash Hazard Standards, The Burning Question':

*"…there is a **serious anomaly between NENS 09 and NFPA 70E arc flash PPE specification**. As per NENS 09 table, adequate protection for 10 cal/cm$^2$ heat flux is provided by 185 gsm cotton drill clothing. This is normal every day workwear in Australian industrial sites. However, as per NFPA 70E, incident heat energy of 10 cal/cm$^2$ requires Hazard Risk Category 3 FR clothing along with arc flash suit hood. This is a huge difference. To the best of knowledge of the author, there has been no serious criticism in the available literature with regard to NFPA 70E arc flash protection PPE specifications."*

*"It can be noted that heat flux equations in NENS 09 do not consider concept of 'arc current' which can be much lower than bolted fault currents in LV systems. **It is also not clear whether these equations are for 'open air' or 'arc in a box'. NENS 09 does not provide adequate documentation on the research background for the equations specified for heat flux calculations."***

***In conclusion, major revisions to NENS 09 arc flash protection specification and heat flux calculation equations are necessary before it can be used effectively by Australian industries."***

## 10.0 APPENDIX C (WHAT IS AN ARC FLASH?)

An arc flash is the explosive release of heat and light energy as a result of an electrical fault where electrical current is partially or fully passing through air rather than a conductor. The temperature of an arc flash can exceed 19,000°C which is 4 times hotter than the surface of the sun. There are other dangers associated with arc flashes such as noise, pressure waves and solid particles such as molten copper which can be ejected at high velocity as a result of the blast.

**An arc flash explosion from a 21kV padmount switch [1]**

**Aftermath of an arc flash explosion [2]**

Whilst the injury normally reported is skin burns, the hazards extend to other things as well, including electrocution if the arc extends to make contact with the person.

### 10.1.1 Causes of death from arc flash

- An electric shock induced fall can cause fatal physical injuries.
- When the skin is severely burnt, large quantities of liquid are brought to the burnt areas to aid in the healing process. This creates a stress on the renal system and could result in kidney failure.
- Severe trauma from massive burns can cause a general systemic failure.
- Burnt internal organs can shut down causing death. Thus, the more critical the organ that is burnt, the higher the possibility of death.
- The pressure front from the blast can cause severe injury to the lungs, called blast-lung, resulting in death.
- Heart failure can result from fibrillation and/or paralysis.

### 10.1.2 Causes of injury from arc flash

- The reflex action caused by the passage of current flow can cause falls resulting in cuts, abrasions, or broken limbs.
- Nerve damage from shock or burns can cause loss of motor function, tingling, and/or paralysis.
- Burns, both thermal- and current-induced, can cause extremely long duration and intensely painful suffering. Third-degree burns may require skin grafting to heal.
- The light intensity, molten metal and/or burns to the eyes can cause blindness.
- The concussion of a blast can cause partial or complete loss of hearing.
- Current-induced burns to internal organs can cause organ dysfunction.
- The superheated plasma may be inhaled, causing severe internal burns.
- Metal vapours may be inhaled filling the lungs with toxic residues.

Source: Electrical Safety Handbook

#### 10.1.3 Incident energy and burns

The degree of injury a person will sustain when exposed to an arc flash is proportional to the arc flash energy. The arc flash energy is predominantly based on the following characteristics:

- The fault level
- The fault clearance time
- The distance away from the arc
- The distance between the arcing conductors

Incident energy (at a certain distance) is commonly measured in calories per square cm (cal/cm2). The table below illustrates the degree of burns, and the level of incident energy required.

| Burn level | Energy (cal/cm$^2$) | Layers involved | Prognosis |
|---|---|---|---|
| First | | Epidermis only | Similar to sunburn. Painful, but generally heals well in 5 to 10 days |
| Second | 1.2 | Extends partially into dermis | Blistering, possible local infection and scarring, deep 2$^{nd}$ degree burns may require excision and skin grafting.<br>Can be fatal if extended over a large proportion of body area.<br>Can ignite cotton clothing |
| Third | 8 | Extends fully into dermis | Scarring, contractures, amputation, can be fatal. |
| Fourth | | Extends through entire skin and into underlying fat, muscle and bone | Amputation, significant functional impairment, can be fatal. |

**2$^{nd}$/3$^{rd}$ degree burns [3]**

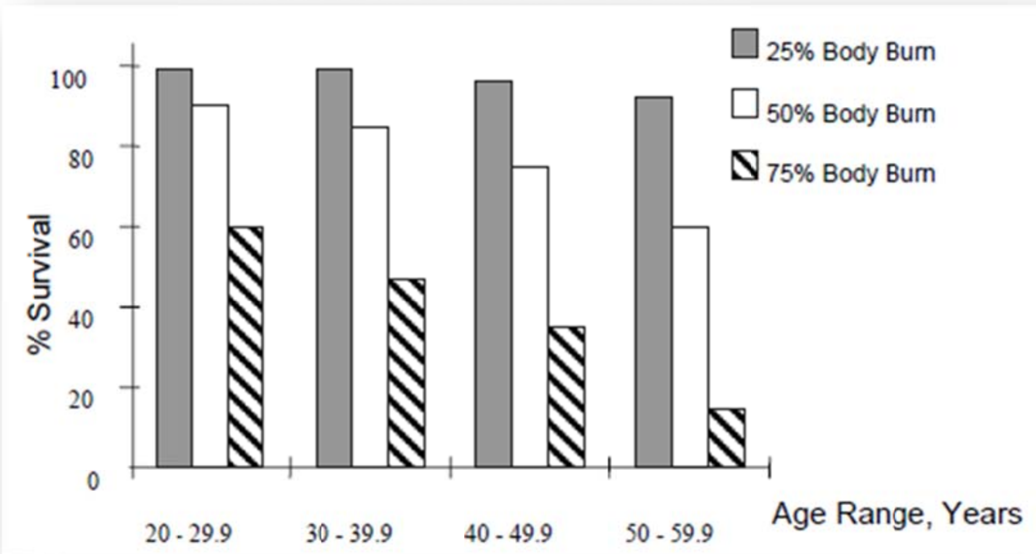


Endeavour Energy

**3rd/4th degree burns [4]**

### 10.1.4 Mortality risk

When burns extend to a significant proportion of a person's skin area, there is a significant probability of death as a result of complications such as infection and subsequent organ failure.




Source: Practical Solution Guide to Arc Flash Hazards

# 11.0 APPENDIX D (NEW ZEALAND ARC FLASH CODE OF PRACTICE)

Whilst this document is not authoritative in Australia, it is a very relevant industry guideline, and the principles within appear to be sound and in line with international best practice.


**1. PURPOSE**

This Guide provides information on, and clarifies issues and requirements relating to, the management of arc flash hazards in the Electricity Supply Industry (ESI) in NZ. The Guide also establishes a policy for the evaluation of arc flash hazards.

## 4. LEGISLATIVE AND OTHER RELATED REQUIREMENTS

4.1 New Zealand

In NZ an arc flash will normally be classified as a significant hazard under the Health and Safety in Employment Act due to the potential for serious harm. Therefore arc flash hazards must be addressed according to the hierarchy of the Act, i.e.;

- Eliminated, or
- If it cannot be eliminated, then isolated, or
- If it cannot be isolated then minimized and PPE provided.

Arc flash may also be considered a significant hazard to the public and therefore would need to be managed under the Safety Management Systems required under the Electricity Act for the Electricity Supply Industry.

## 5. POLICY

Asset owners shall carry out an assessment to determine potential exposure to an electric arc for employees and contractors who work on or near energised parts, equipment or lines in accordance with section 8 of this Guide. If the assessment determines that a potential employee exposure to an incident energy of greater than 1.2 cal/cm$^2$ (5.0 J/cm$^2$) exists the asset owner shall take all practicable steps to;

- Eliminate the exposure, i.e. reduce it to no more than 1.2 cal/cm$^2$, or
- If elimination is not practicable, isolate the exposure from employees, or
- If elimination or isolation is not practicable, minimize the exposure and provide protective equipment to employees.

Preferred means of achieving a reduction in exposure include;

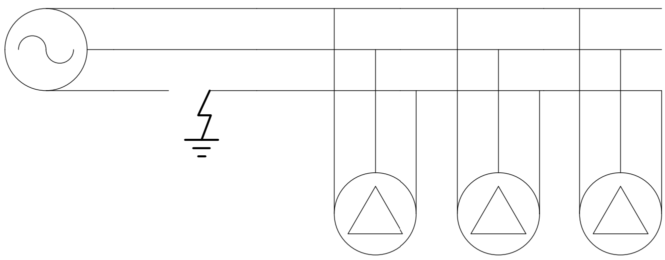
- Faster protection operation,
- Increased operational distance from the equipment,
- Retrofitted modifications to equipment (refer section 10),
- Establishing limited approach boundaries for persons not working on or near the equipment,
- Remote operation of the equipment,
- Requiring employees/contractors to wear industrial workwear that has an effective arc rating not less than the anticipated level of arc energy to which the employee is exposed.

A programme for assessment of all assets shall be in place by no later than 30/6/2012, with assessments completed by no later than 31/12/2013.

# 12.0 APPENDIX E (LINES DOWN CASE ANALYSIS)

The following event occurred on the Endeavour Energy network a few years ago and this type of event is not uncommon. Members of the public reported that lines were on the ground and witnesses saw arcing and smoking for 20 to 30 minutes before the fault was manually isolated from the supply. These types of events have a significant likelihood of fatal potential, and there is the precedence of a fatality via this means in the Endeavour Energy network.

In this case, as is not uncommon, the line remained energised only via the windings of downstream transformers. That is, it was not connected directly to the source, as is illustrated in the image below.

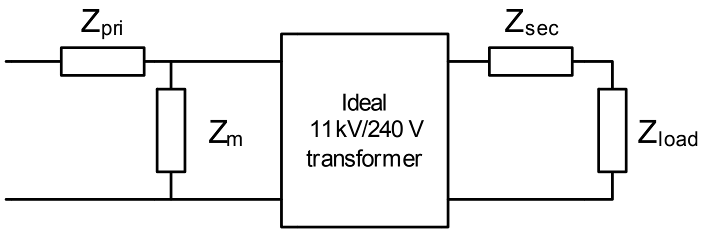


In these cases, even if fault resistance is low or zero, the fault current can be very low, and is primarily based on the impedance of the load connected to downstream transformers, as is illustrated by the technical analysis to follow.

A single winding model of a distribution substation transformer and typical impedances are shown in the figure and table below. The magnetising current of single substation is around 50 to 100mA. $Z_{primary}$ and $Z_{secondary}$ are in the order of 40Ω and 0.1Ω respectively and are insignificantly low when compared to $Z_{load}$ (if there is any significant load), so the effective impedance of the transformer primary winding is primarily dependant on the load impedance.



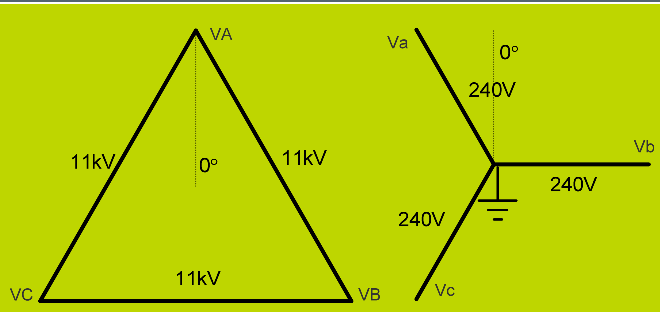
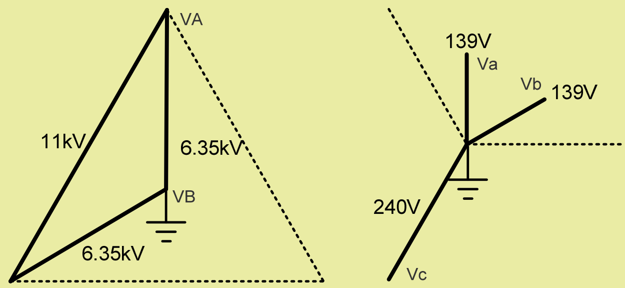
Endeavour Energy




| Parameter | Typical impedance |
|---|---|
| Zpri | 40Ω |
| Zmag | 100,000Ω |
| Zsec | 0.1Ω |

Assuming no fault resistance, the effect of the fault on the 3 phase winding voltages of a delta-star Dyn11 transformer is shown in the figures below. The voltage across the two windings that are connected to the fault will drop and change in angle. On the secondary side, the voltages will also drop and change in angle. The phases are at reduced voltages and are no longer 120 degrees apart. Some load will trip out, some load (e.g. constant power devices such as switch mode power supplies) will draw more current, and purely resistive loads keep the same impedance drawing less current. Embedded generation such as solar panels is likely to trip out resulting in an apparent decrease in impedance.

At the time of the incident, the estimated load current connected downstream of the fault was approximately 5A of primary current. Assuming no fault resistance and only constant impedance load, the calculated residual earth fault current in this case is 1.7A.

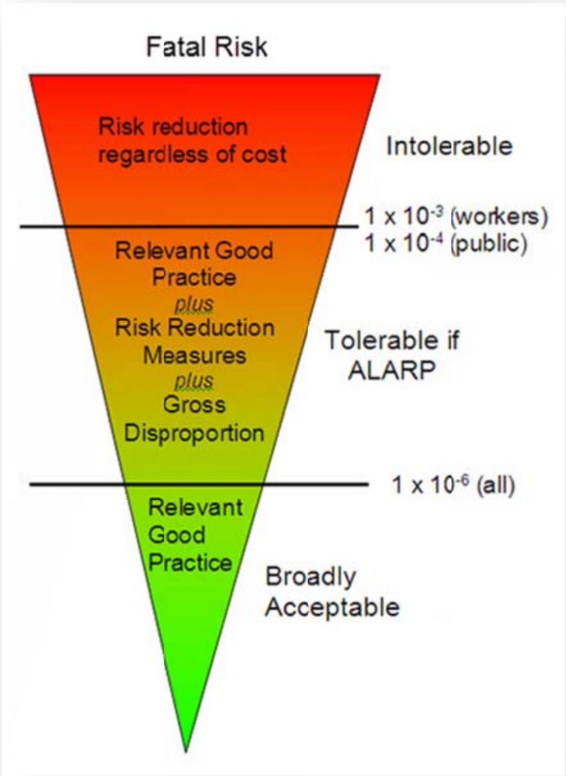
| Condition | Voltage phasors |
|---|---|
| Pre-fault |  |
| Post-fault |  |

| | Pre-fault | | Post-fault | |
|---|---|---|---|---|
| | Magnitude | Angle | Magnitude | Angle |
| **VA** | 6351V | 0° | 6351V | 0° |
| **VB** | 6351V | -120° | 0V | 0° |
| **VC** | 6351V | 120° | 6351V | 120° |
| | | | | |
| **Va** | 240V | 30° | 139V | 0° |
| **Vb** | 240V | -90° | 139V | -60° |
| **Vc** | 240V | 150° | 240V | 150° |
| | | | | |
| **Ia** | 132.3A | 30° | 76.4A | 0° |
| **Ib** | 132.3A | -90° | 76.4A | -60° |
| **Ic** | 132.3A | 150° | 132.3A | 150° |
| | | | | |
| **IA (winding)** | 2.89A | 210° | 1.67A | 180° |
| **IB (winding)** | 2.89A | 90° | 1.67A | 120° |
| **IC (winding)** | 2.89A | -30° | 2.89A | -30° |
| | | | | |
| **IA (line)** | 5.00A | 0° | 4.41A | -19° |
| **IB (line/fault)** | 5.00A | -120° | **1.67A** | **-120°** |
| **IC (line)** | 5.00A | 120° | 4.41A | 139° |

It can be seen that the residual current (earthfault current) in this case is 1.67A compared to a pre-fault load current of 5A. This assumes star connected constant impedance load with a power factor of unity and a fault resistance of zero. Whilst there are several overly-simplistic assumptions in this analysis, it remains conceptually correct. In many cases of lines down, the fault will remain connected only through the windings of downstream distribution transformers, and in these cases the maximum residual current will be proportional (33% if all loads are constant impedance) to the downstream connected load current, which will usually be very small. A 1A or lower SEF pickup will increase the likelihood of these types of faults, as well as normally fed high impedance faults being detected.

# 13.0 APPENDIX F (COST BENEFIT ANALYSIS)

## 13.1 Modern relays - faster clearance times




### 13.1.1 Individual risk

The highest internal risk exposure is believed to be the subset of District Operators who regularly switch plant, and have regular exposure to abnormal network situations. There are approximately 70 district operators, and within this subset the estimated serious injury or death accident rate is 1 in 5 to 50 years. This represents an individual risk level of 1 in 350 to 1 in 3500 per person per annum. This risk lies within the upper tolerable or intolerable zone according to international best practice on ALARP (the threshold is 1 in 1000 for fatalities of workers).

Assuming this level of risk does not lie within the intolerable zone, the high level of risk would warrant a safety cost benefit disproportionate factor of 10 for the purposes of an ALARP grossly disproportionate test. A lower but similarly high Other subsets of workers and the public would be exposed to lower levels of individual risk, but given the frequency and nature of occurrences a disproportionate factor below 10 cannot be easily justified for this risk.

### 13.1.2 Control quantitative CBA

A serious arc flash injury event occurs on the distribution network approximately once per year on average. This is based on some of the known occurrences over the last 5 to 10 years.

This project is only applicable to 36% of distribution feeders on the Endeavour Energy network. The remaining feeders already have modern relays which are capable of the highset.

The ***Value of a Statistical Life (VSL)*** has been taken to be $4.45M (in 2015), which is consistent with the guidance provided by the Australian Government's Office of Best Practice Regulation for preparing Regulatory Impact Statements (Best Practice Regulation Guideline Note: Value of statistical life, November 2008). This figure is consistent with Australian and international best practice, and was used by the Powerline Bushfire Safety Taskforce to value lives lost in the Black Saturday bushfires to conduct a quantitative cost benefit analysis to assess the various risk mitigation control options. The recommendations of this report were supported by the Victorian Government.

The injury weighting factor (injury to fatality factor) for a typical serious arc-flash accident has been taken to be 0.441 which is the injury to fatality adjustment weighting as published by the Australian Institute of Health and Welfare for typical injuries expected from a serious arc flash accident, that is, resulting in burns to >20% of the surface area of the body.

The typical level of injury reduction as a result of this control is substantial. At typical working distances, say 40 to 70cm, the clearance time can be the difference between being protected by a cotton shirt, and receiving 2nd or 3rd degree burns. The risk/injury reduction factor as a result of this mitigation control is considered to lie between 0.3 (30% reduction in injury) and 1.0 (total avoidance of injury) across the majority of serious accidents. A mitigation factor of 0.6 has been selected as a best estimate for these cost benefit calculations.

The life of the control is considered to be 20 years, that being the life expectancy of modern protection systems.

In summary, the factors used for the cost benefit analysis are:

- Event frequency = 1 per annum
- Percentage of network covered by this program = 0.36 (only 36% of feeders are covered)
- Injury weighting factor = 0.441 (The injury to death weighting factor for a serious burn accident)
- Reduction in impact as a result of this control = 0.6 (considered to lie between 0.3 and 1.0)
- Value of a Statistical Life (VSL) = $4.45M in 2015 dollars.
- A grossly disproportionate factor (DF) = 10
- 20 year time frame (anticipated life expectancy of modern protection systems)
- Discount (uprating) factor of 4% to safety benefits

$$Safety\ Benifits = VSL\ \times InjuryFactor \times\ P_{reduction}\ \times \frac{1}{D}\left[1-\left(\frac{1}{1+D}\right)^{Y}\right] \times DF$$

$$= \$\mathbf{134}\ \boldsymbol{million}\ NPV$$

Given these parameters, the NPV of the safety benefit, is $13.4 million, (or $134 million using a disproportionate factor of 10) over the 20 year life of the relays.

### 13.1.3 Sensitivity analysis

Adjusting values to non-conservative levels:

| Impact | NPV ($M) |
|---|---|
| Frequency reduced to 0.5pa | 67 |
| Injury weighting factor for burns <20% of body (0.158) | 48 |
| Reduction in impact of control reduced to 0.2 | 45 |
| Disproportionate factor reduced to 3 | 40 |
| Life of control reduced to 10 years | 53 |

### 13.1.4 Summary

The grossly disproportionate value of the reduction in arc-flash injury has been calculated to be $134 million NPV. The cost of the control even with non-conservative values still results in a cost benefit justified result which exceeds the cost of the control. Given that the cost of the project is substantially lower than the cost of the benefit, the control is considered to be a requirement under section 17 of the NSW Work Health and Safety Act 2011 even without considering the other benefits of this project.

## 13.2 Direct and indirect contact risk mitigation (core balance CT's)

There are several fatal high-impedance fault events recalled by longstanding employees of Endeavour Energy:

- The fatality of a boy in the Blue Mountains area as a result of back fed lines on the ground.
- The fatality of a crane operator who was unaware of contact with 11kV lines in the Hawkesbury/Cattai area. 1995 or 1996.
- Multiple fatalities of persons in a car accident in the Blue Mountains. Mains fallen on car, when the occupants got out of the car, they received fatal electric shocks.

Here say is that the basis for the installation of core balance CT's and more sensitive settings on numerous reclosers in the Blue Mountains resulted from a court recommendation or directive as a result of the latter fatalities. These core balance CT's along with their more sensitive settings have recently been removed.

Based on these events as well as media reports on fatalities in other network areas, a fatality is expected to occur as a result of a non-detected high impedance fault in the Endeavour Energy network in the order of once every 5 to 50 years. 1 in 10 years has been selected. It should also be noted that bushfire risk is also a factor, and multiple fatalities is plausible. The individual risk level varies significantly. Considering workers, and particularly the recent Essential Energy fatality, the risk level to electrical workers is considered to lie between 1 in 10,000 and 1 in 100,000 [per person per annum]. An appropriate disproportionate factor for such an individual risk level is considered to lie between 5 and 10.

This project is only applicable to 36% of distribution feeders on the Endeavour Energy network.

The Value of a Statistical Life (VSL) has been taken to be $4.45 million (in 2015), which is consistent with the guidance provided by the Australian Government's Office of Best Practice Regulation for preparing Regulatory Impact Statements (Best Practice Regulation Guideline Note: Value of statistical life, November 2008). This figure is consistent with Australian and international best practice, and was used by the Powerline Bushfire Safety Taskforce to value lives lost in the Black Saturday bushfires to conduct a quantitative cost benefit analysis to assess the various risk mitigation control options, the recommendations of which were supported by the Victorian Government.

The typical rate of detection of otherwise non-cleared high impedance faults that will be detected by the more sensitive setting is considered to be in the order of 30%, but could foreseeably range from 10% to 80%. In some areas of the Blue Mountains, the soil resistivity is such that a solid earth fault would result in fault current in the region of 3A, and so the detection rate in this area could be very substantial.

The life of the core balance CT installation is likely to be the remaining life of the substation. Any protection relay replacement within this period will occur irrespective of the core balance installation. The life is considered to be 40 years.

In summary, the factors used for the cost benefit analysis are:

- Event frequency = 1 in 10 per annum
- Percentage of network covered by this program = 0.36 (only 36% of feeders are covered)
- Reduction in impact as a result of this control = 0.3 (considered to lie between 0.1 and 0.8)
- Value of a Statistical Life (VSL) = $4.45 million in 2015 dollars.
- A grossly disproportionate factor (DF) = 10

- 40 year time frame (anticipated life expectancy of the core balance CT and substation)
- Discount (uprating) factor of 4% to safety benefits

$$Safety\ Benifits = VSL \times P_{reduction} \times \frac{1}{D}\left[1 - \left(\frac{1}{1+D}\right)^{Y}\right] \times DF$$

$$= \$\mathbf{49.5\ million}\ NPV$$

Given these parameters, the NPV of the safety benefit, is $5 million ($49.5 million considering a grossly disproportionate factor of 10) over the 40 year life. Given that the cost of the project is substantially less than the cost of the benefit of 2.7 million ($2.2 million NPV), this control is not grossly disproportionate to the benefit, and the control is considered to be a requirement for a defensible position under section 17 of the NSW Work Health and Safety Act 2011.

### 13.2.1 Sensitivity analysis

Adjusting values within their band of tolerance:

| Impact | NPV ($M) |
|---|---|
| No changes | 49.5 |
| Frequency reduced to 1 in 50 years | 9.9 |
| Detection rate only increased by 5% (instead of 30%) | 8.3 |
| Detection rate increased to 70% (instead of 30%) | 115 |
| Life of control reduced to 20 years | 15.2 |
| Frequency rate reduced to 1 in 50 years, and detection rate only 10% | 3.3 |

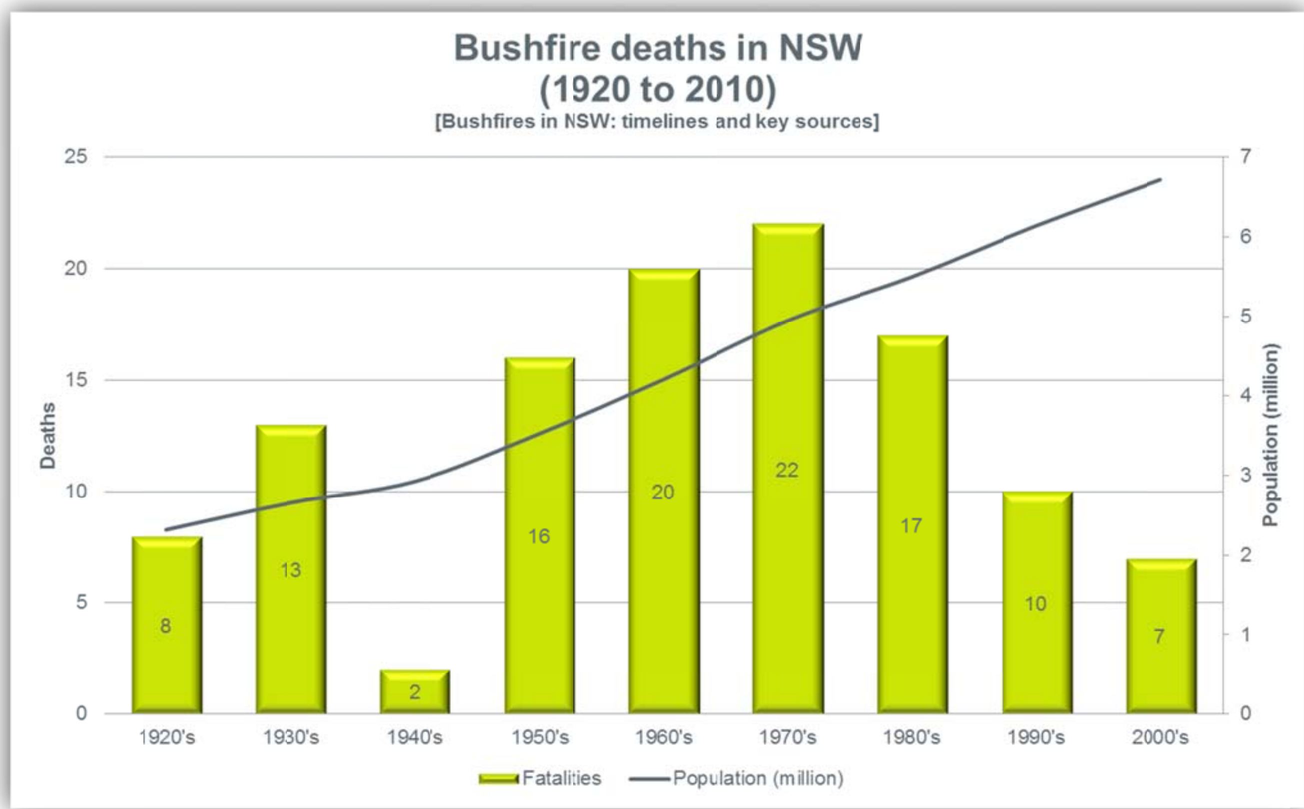
### 13.2.2 Summary

The value of the reduction in risk of death associated with the installation of core balance CT's which will reduce the risk of undetected earth faults has been calculated to be in the order of $49.5M NPV. Given that the cost of the control is much lower than this ($2.6M), the control is considered to be a requirement for a defensible position under section 17 of the NSW Work Health and Safety Act 2011.

## 13.3 Bushfire risk mitigation

### 13.3.1 NSW bushfire risk – typical risk

Fatalities attributed to bushfires from 1920 to 2014 are detailed against population in the histogram below. It is clear that there has been a downward trend since the 1980's, possibly due to better controls in spite of increasing exposure (population).



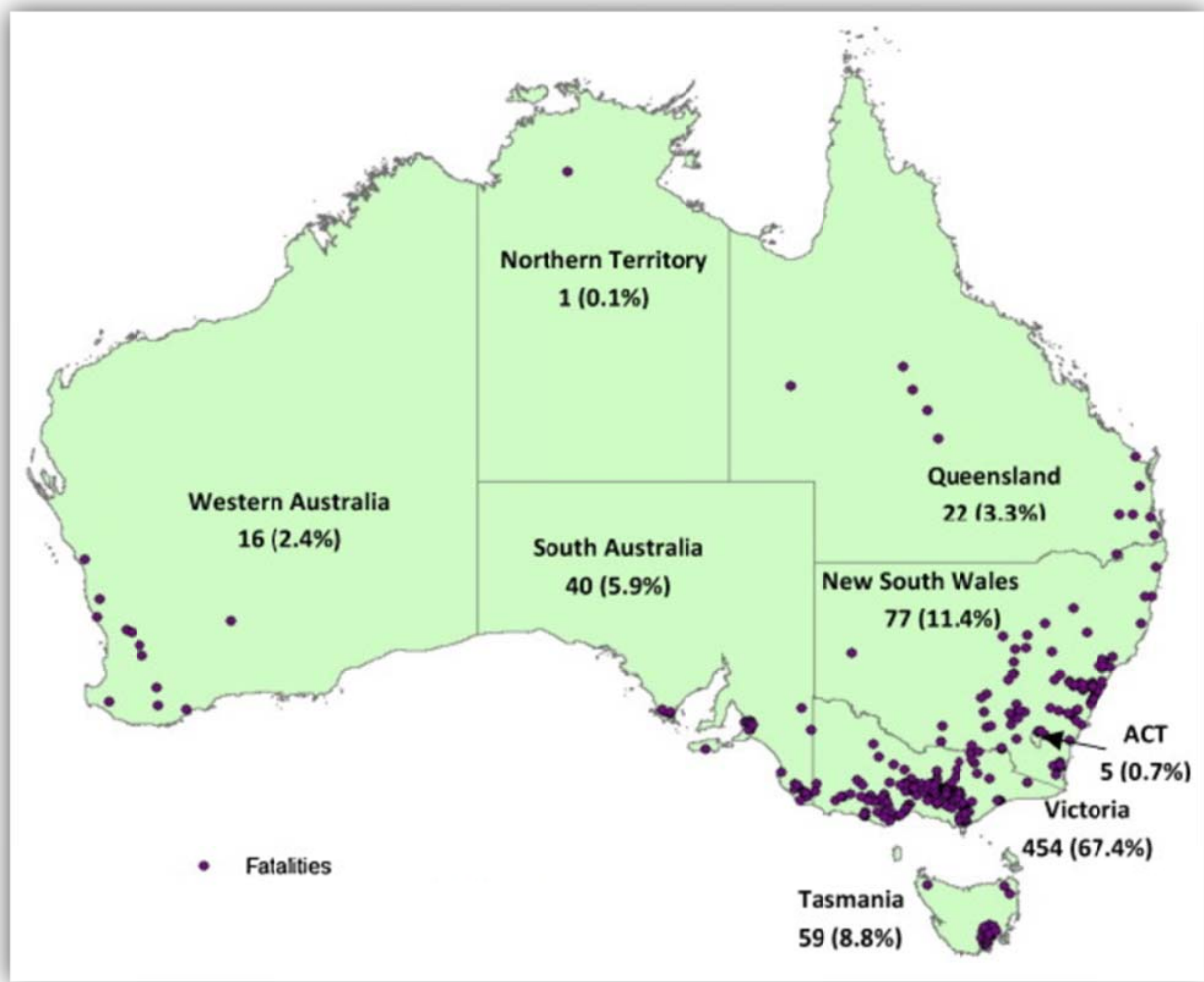

| Period | Deaths (NSW) | Actual fatal impact level (deaths pa) |
|---|---|---|
| **Last 95 years** (1920 to 2014) | 117 | 1.23 |
| **Last 30 years** (1985 to 2014) | 23 | 0.77 |
| **Last 15 years** (2000 to 2014) | 9 | 0.6 |

From these statistics, the current bushfire risk for events with lower than 20 fatalities is taken to be that of the last 30 years which is approximately 0.8 [deaths per annum].

### 13.3.2 NSW bushfire risk – likely worst consequence

The data above provides a good insight into high frequency lower impact events, but doesn't provide a high degree of clarity on lower frequency higher consequence events where the number of fatalities is say greater than 20.

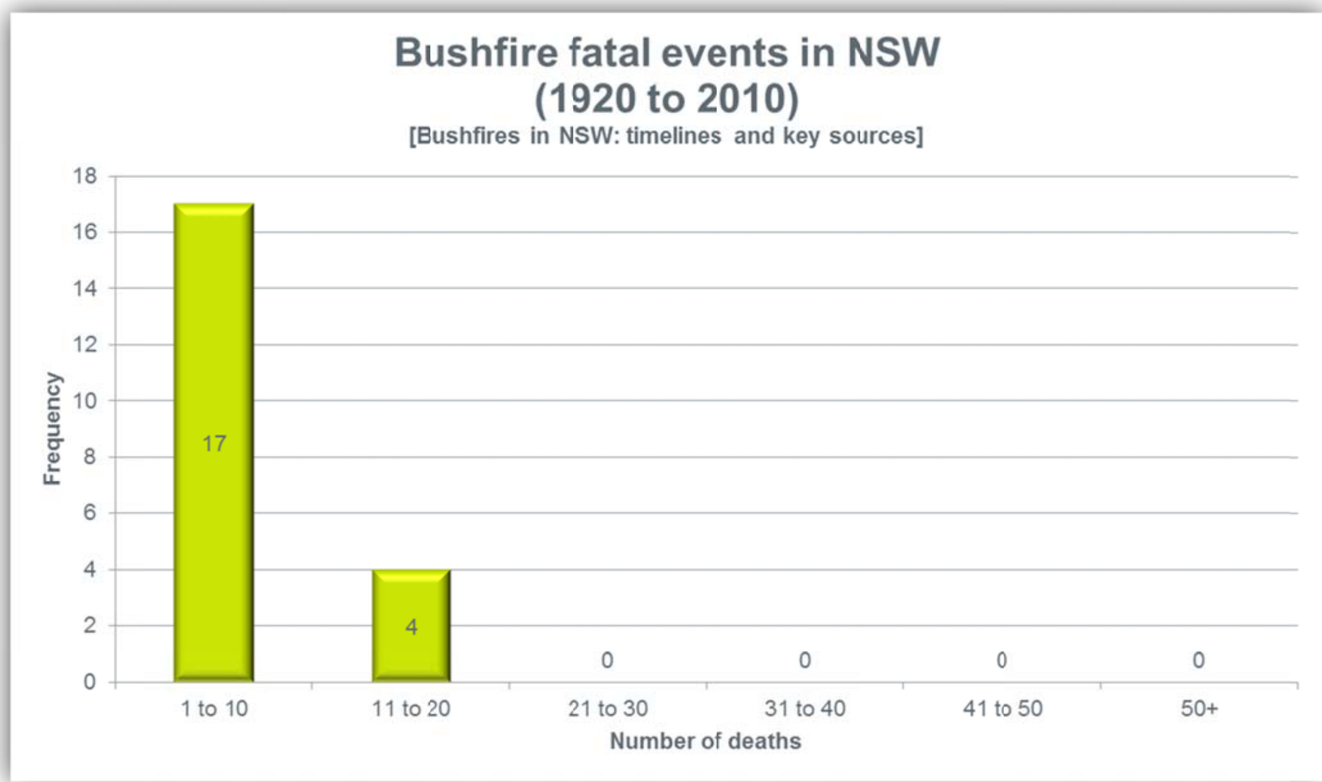
Black Saturday [Powerline Bushfire Safety Taskforce: Final Report] says: *"the environmental conditions in Victoria are such that Victoria is more vulnerable to catastrophic bushfires than NSW",* and the information in the diagram below, which illustrates the number of bushfire fatalities directly attributed to bushfires in all states of Australia from 1901 to 2011, supports this claim.




**Bushfire fatalities (direct result) in Australia (1901 to 2011)**

**[Environmental circumstances surrounding bushfire fatalities in Australia in 1901-2011, 2013}**

According to Wikipedia, Victoria have had 8 events since 1920 where the number of fatalities exceeded 20. By comparison, NSW have had 0. The average risk level in Victoria for these events is: frequency average 1 in 12 years, consequence average 60 fatalities. Given that in NSW, a similar event has been absent for at least 95 years, this would imply that the frequency of these very high consequence events is much lower than that of Victoria, and probably lies between 1 in 50 years, and 1 in 200 years. For this assessment, it is considered that the likely worst consequence in NSW is suitably represented by 60 fatalities, once every 50 years, which is a risk of 1.2 [fatalities per annum].




### 13.3.3 Total risk level in NSW

Considering both lower and higher consequence events, the fatal risk level in NSW is taken to be 2 fatalities per annum. To factor in injuries, the total has been increased by 25% to 2.5 fatalities per annum. Whilst property loss and other costs can be attributed to bushfires, this has not specifically been factored into this safety case. The total risk level of 2.5pa with a grossly disproportionate factor of 10, represents over $1.1 billion every 10 years. Factoring in property loss would not result in a significant change.

| | Risk level (fatalities pa) |
|---|---|
| Fatal events (<20) | 0.8 |
| Very high consequence events (>20) | 1.2 |
| Injuries (25% of fatalities) | 0.5 |
| **Total risk level in NSW** | **2.5** |

### 13.3.4 Endeavour Energy network area

Approximately 40% of NSW bushfire fatalities in the past 95 years have been in the Endeavour Energy network area, and this figure is considered to be appropriate for apportioning future risk to the network area.

### 13.3.5 Electricity started fires

It is clear that in general the majority of bushfires are not caused by electrical networks, however the proportion of fires linked to electrical networks on days of extreme fire danger seems to be much higher.

*“Although the proportion of fires that are caused by electricity infrastructure is low—possibly about 1.5% of all ignitions in normal circumstances—on days of extreme fire danger the percentage of fires linked to electrical assets rises dramatically. Thus, electricity-caused fires are most likely to occur when the risk of a fire getting out of control and having deadly consequences is greatest.”* [2009 Victorian Bushfires Royal Commission Final Report Summary, July 2010]

According to the Victorian Bushfire Royal Commission Final Report, 5 out of 11 of the Black Saturday bushfires of 2009 (173 fatalities), and 4 out of 8 of the Ash Wednesday bushfires of 1983 (47 fatalities), were caused by electrical networks.

It is therefore conservatively considered that electrical networks contribute to 50% of bushfire fatal risk even if the proportion of actual electrical fire starts is much lower than this.

#### 13.3.6 MV Networks

The relevant controls under this business case only control risk on the MV (medium voltage) distribution network. The MV network represents approximately 50% of the Endeavour Energy network by length of conductors. Assuming that the risk is proportional to conductor length, and the fire start probability is not influenced by voltage level, this control is limited to influencing only 50% of the Endeavour Energy electrical network.

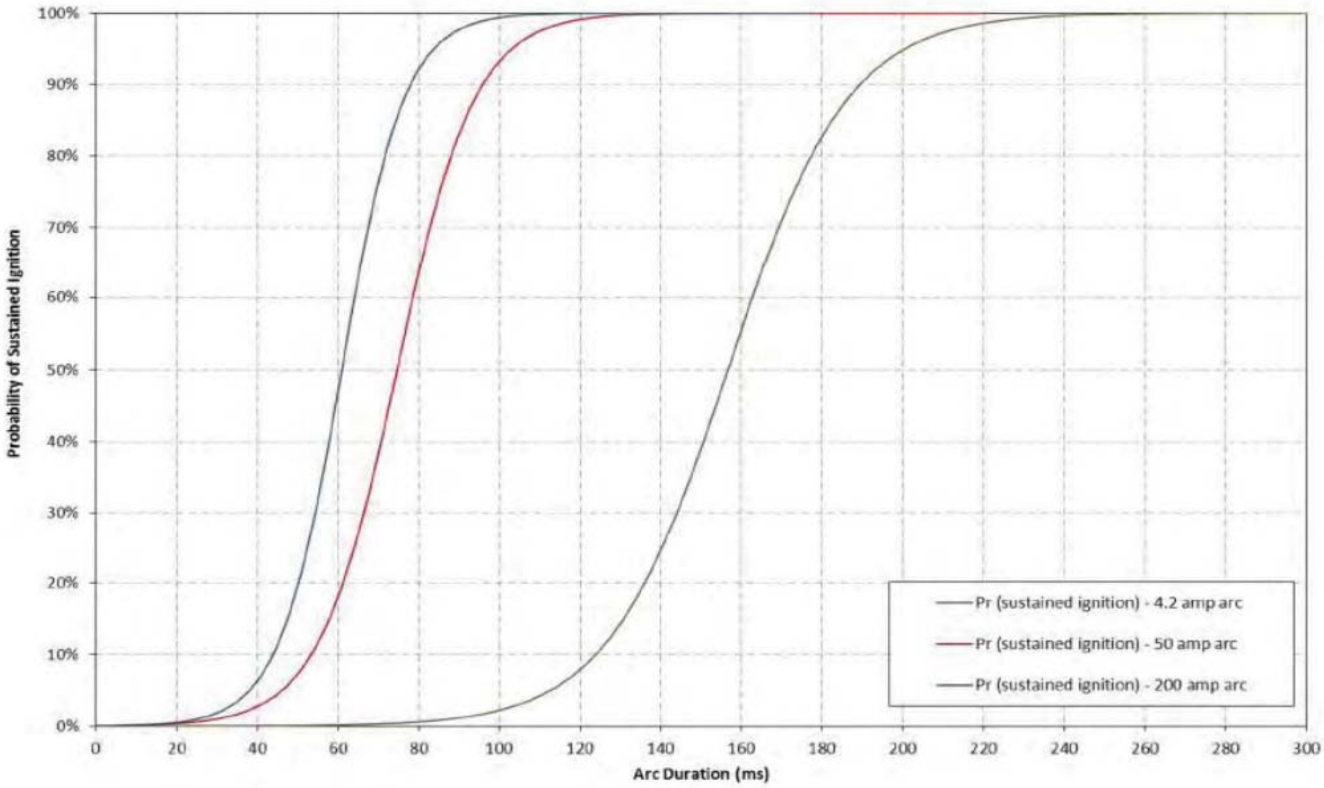
#### 13.3.7 Coverage

This particular program only covers 36% of network feeders.

#### 13.3.8 Control effectiveness

The controls relevant to bushfire risk, being high-sets, a reduction in inverse curve grading margin, and adding additional sensitivity to existing SEF protection are considered to have limited effectiveness in preventing bushfires on the MV network. The reasons for this include:

- The majority of faults (probably over 90%) in bushfire prone areas would not be covered by a high-set (i.e. typically >3-4kA) at the zone breaker because they are either much lower in magnitude or they are covered by another protection device (such as line recloser or fuse). Additionally, the high-set does not guarantee the prevention of a fire.
- The clearance times of intermediate level faults, that is, between the overcurrent/earth fault pickup (typically 100 to 400A), and the high-set (typically 3-4kA) is not substantially changed (changed typically by only 10% or so).
- Not all high-impedance faults can be detected, and even if they are, the SEF protections typically operate in a minimum of 5 to 10s. As illustrated in the figure below, the clearance time required to prevent network faults from igniting prone materials under worst case dry conditions with typical low level faults (from 4A to 200A) ranges from 20ms to 200ms. This is much faster than the protection can operate.



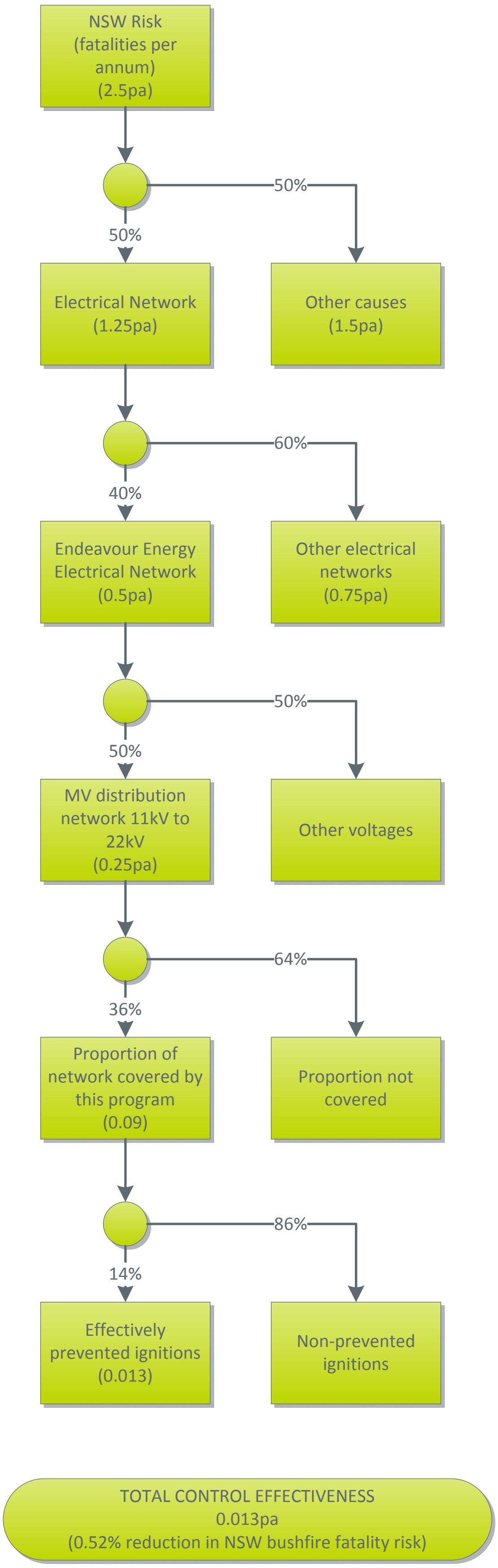

**Ignition probability against arc duration at 45degC, and 10km/h wind speed for hay/straw at 5% moisture (Powerline Bushfire Safety Taskforce: Final Report)**

The following table estimates the total effectiveness of the controls in this business case in preventing a bushfire ignition on the MV network.

| Fault current | % of faults relating to | Mitigation value | Total | Comments/basis |
|---|---|---|---|---|
| 0A - 1A | 10% | 0% | 0% | Below the 1A pickup, the fault remains undetectable, therefore the risk remains unchanged. |
| 1A - 4A | 20% | 15% | 3% | Whilst detection is achieved, the fault still remains energised for 5 to 10 seconds irrespective of detection. Under extreme bushfire danger conditions, and given lines down on flammable material, it has been demonstrated that bushfire ignition is almost certain in less than 200ms. There may be some circumstances where the probability of prevention is greater than this. |
| 4A - 400A | 20% | 0% | 0% | Between the SEF pickup and overcurrent pickup, the clearance time remains unchanged. |
| 400A - 3.6kA | 40% | 10% | 4% | Above the overcurrent pickup, the inverse characteristic of the relay can be typically 10% faster with a modern numerical relay due to tighter grading margins and finer time multiplier settings. 10% faster means a 10% reduction in energy. It is conservatively assumed that energy is proportional to likelihood of bushfire ignition. |
| >3.6kA | 10% | 70% | 7% | Above the high-set pickup, typical fault energy reduction is 70% due to similar reduction in clearance time. It is conservatively assumed that energy is proportional to likelihood of bushfire ignition. |
| | | **TOTAL MITIGATION** | **14%** | |

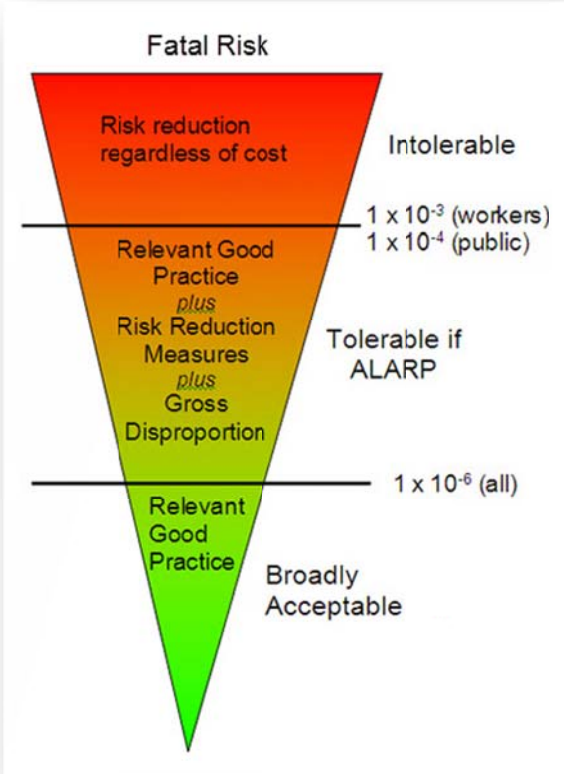
Note: This is an estimate based on engineering judgement. Robust data is not currently available.

### 13.3.9 Overall risk tree (control effectiveness)



### 13.3.10 Individual risk level

Overall, the average individual risk level in NSW considering a risk level of 2.5 [fatalities per annum] and a population of 7.5 million is 0.33 in 1,000,000 [per person per annum] which lies in the broadly acceptable region. However, a smaller proportion of the population live in bushfire prone areas. The average individual risk level in the Blue Mountains and Southern Highlands considering a population of 125,000, and considering a risk level of 1 pa (40% of total Endeavour Energy network area risk and including non-electrical network caused fires) is 8 in 1,000,000 [per person per annum]. It is further acknowledged that within these areas, perhaps a smaller proportion of the population is exposed to a much greater risk than the average person. If the highest exposed individual is exposed to 10 times the risk of the average, this would result in an individual risk level of 80 in 1,000,000 (1 in 12,000) p.a., and this would perhaps justify a grossly disproportionate factor of 10.




### 13.3.11 Relative risk

People's emotive aversion to bushfires is understandable, however from a rational standpoint, relative to other risks, such as traffic accidents, it is not exceptional. For example, in the 5 year period between 2004 and 2008 in NSW alone there were 171 fatalities and 5060 injuries resulting from vehicle impacts with power poles [RTA 2009]. In the same period there were 0 fatalities from bushfires. Prudence dictates that we spend societies limited resources where they will likely give the greatest benefit, so this report has considered all safety risks objectively/impartially rather than factoring in societies aversion biases.

### 13.3.12 Control quantitative CBA

The ***Value of a Statistical Life (VSL)*** has been taken to be $4.45M (in 2015), which is consistent with the guidance provided by the Australian Government's Office of Best Practice Regulation for preparing Regulatory Impact Statements (Best Practice Regulation Guideline Note: Value of statistical life, November 2008). This figure is consistent with Australian and international best practice, and was used by the Powerline Bushfire Safety Taskforce to value lives lost in the Black Saturday bushfires to conduct a quantitative cost benefit analysis to assess the various risk mitigation control options. The recommendations of that report were supported by the Victorian Government.

The life of the control is considered to be 20 years, that being the life expectancy of modern protection systems.

The factors used to assess the mitigation effectiveness for the cost benefit analysis are given above. Other values used include:

- Value of a Statistical Life (VSL) = $4.45M in 2015 dollars.
- A grossly disproportionate factor (DF) = 3
- 20 year time frame (anticipated life expectancy of modern protection systems)

- Discount (uprating) factor of 4% to safety benefits

$$Safety\ Benifits = VSL\ \times P_{reduction}\ \times \frac{1}{D}\left[1 - \left(\frac{1}{1+D}\right)^{Y}\right] \times DF$$

$$= \$\mathbf{17.7\ million}\ NPV$$

Given these parameters, the NPV of the safety benefit is $1.77 million, (or $17.7 million using a disproportionate factor of 10) over the 20 year life of the relays.

### 13.3.13 Sensitivity analysis

The following table highlights the results of the assessment with changes to the input values used above.

| Impact | NPV ($M) |
|---|---|
| Normal (DF = 1) | 1.77 |
| Actual used (DF = 10) | 17.7 |
| Control effectiveness 3% instead of 10% (DF = 1) | 5.31 |
| Control effectiveness 20% instead of 10% (DF = 10) | 35.4 |

### 13.3.14 Summary

The grossly disproportionate value of the reduction in bushfire safety risk has been calculated to be $17.7 million NPV. This contributes further to the justification of this business case. The above value has not factored in property loss, litigation, or political risk.

# 14.0 APPENDIX G (BASIS FOR ALARP QRA)

### 14.1.1 Why use a quantitative assessment?

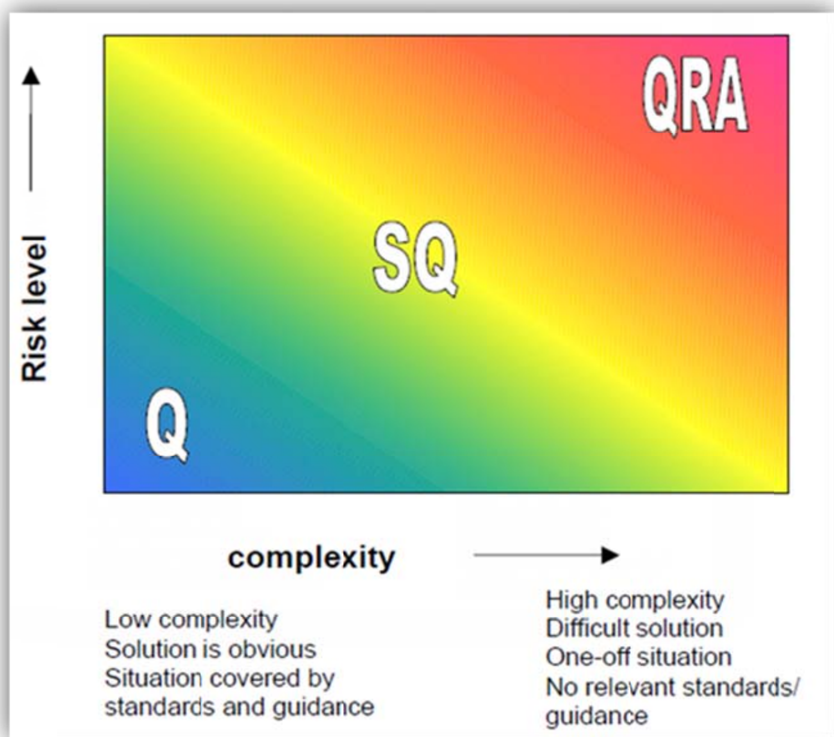
The NSW Work Health & Safety Act requires that risks be ALARP. If risks are not ALARP, people could be needlessly injured and the business and individuals liable for prosecution. However, the government and society also expects us to be efficient and effective. If money is spent on controls which are not effective at reducing risk, this will have a negative impact on businesses and society.

**Ineffective expenditure on risk control measures can also result in an increase in mortality** and risk of injury, both directly (as a result of work to control the risk e.g. infrastructure work can potentially be more risky than the risk being mitigated) and indirectly as a result of socio-economic factors and the relocation of resources. **This is discussed further in the section on risk-risk analysis.**

*"the most recent death from dam failure occurred in Australia in 1929, several people have died in recent decades working on the improvement of dam safety. These facts demonstrate that the activity of reducing risks creates its own risks, quite apart from the wider impacts on risks elsewhere in society."* (Dam safety, economic regulation, and societies need to prioritise health and safety expenditures)

And from a socio-economic/relocation of resources viewpoint, (Safety at any price?, Viselli) says: *"a regulation that yields a cost per life above $50 million (US) would result in a net increase in fatalities"* Other studies estimate the value to be much lower than this.

It is generally insufficient to utilise fully qualitative risk decision making when considering non-trivial risks or significant expense and this methodology may not be sufficient for a robust legal defence. Australian and international best practice safety cost benefit analysis is quantitative or semi-quantitative where the risk level is moderate to high, or where the solution is not obvious, in *support* of safety risk decisions.




**Basis for qualitative (Q), semi quantitative (SQ) or quantitative (QRA) risk assessment**

In balancing the cost of controls with the value of safety improvement it quickly becomes obvious that a dollar value needs to be placed on risk reductions associated with injuries and fatalities. This too is well established and is applied in both Australian and International best practice risk management, though this valuation only applies to low level risk reductions, not substantial risks to any individual.

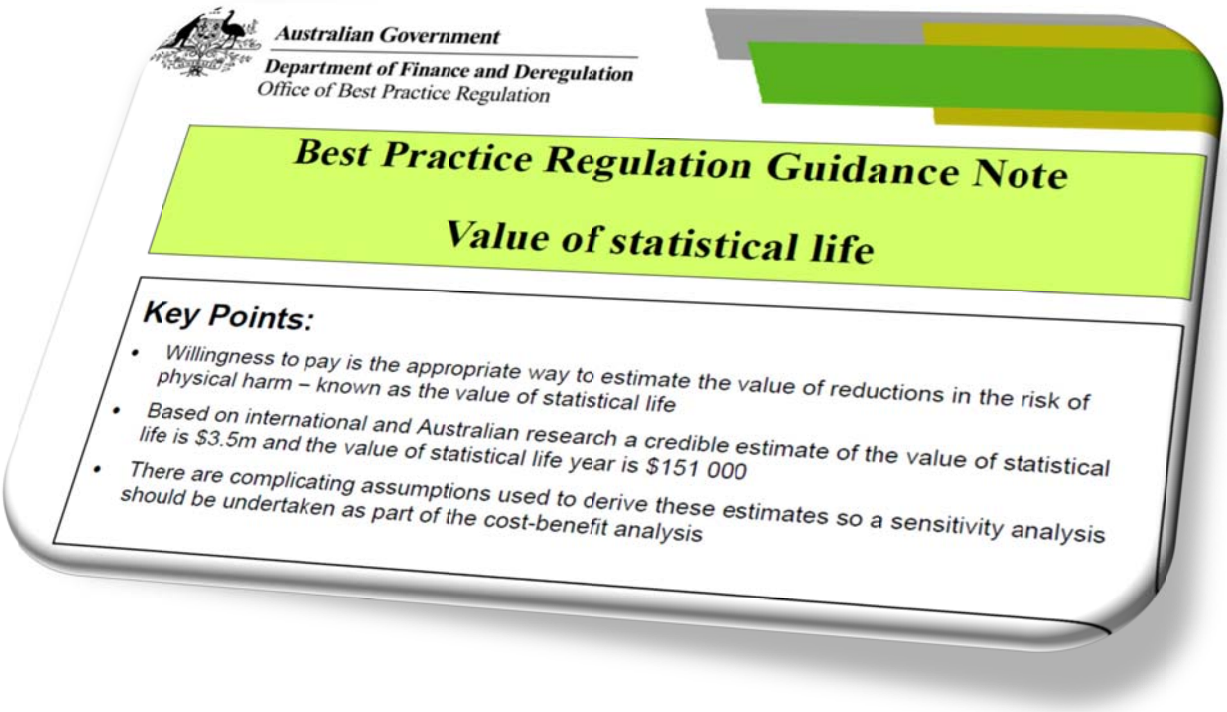
### 14.1.2 The value of a statistical life (VSL) in Australia

The Australian Government Civil Aviation Safety Authority, Cost Benefit Analysis Methodology Procedures Manual 2007: *"Criticism: Application of monetary values to human life – this criticism is misdirected. Lives are not being valued; the values are for reductions in the risks of premature death. Hence the use of the term, the value of statistical life (VSL). Proposals are not designed to protect identifiable individuals from certain death but rather to protect large populations from collective mortality risks. VSL is the relevant concept for judging such proposals."*

Paper to the Australian Government [Dr Peter Abelson]: *"Following our review of research into VSL and VLY and of international guidelines for life and health values, this paper suggests that, in 2007 prices, public agencies in Australia adopt a VSL of $3.5 million for avoiding an immediate death of a healthy individual in middle age (about 50) or younger"*

The Value of a Statistical Life (VSL) in this report has been taken to be $4.45M (in 2015 dollars), which is consistent with the Paper written by Dr Peter Abelson, and then adopted in the guidance provided by the Australian Government's Office of Best Practice Regulation for preparing Regulatory Impact Statements (Best Practice Regulation Guideline Note: Value of statistical life, November 2008).

This figure is relatively consistent with international practice, and was used by the Powerline Bushfire Safety Taskforce to value lives lost in the Black Saturday bushfires in order to conduct a quantitative cost benefit analysis to assess the various power utility risk mitigation control options - the recommendations of which were supported by the Victorian Government.



Australian Government

Department of Finance and Deregulation
Office of Best Practice Regulation

**Best Practice Regulation Guidance Note**

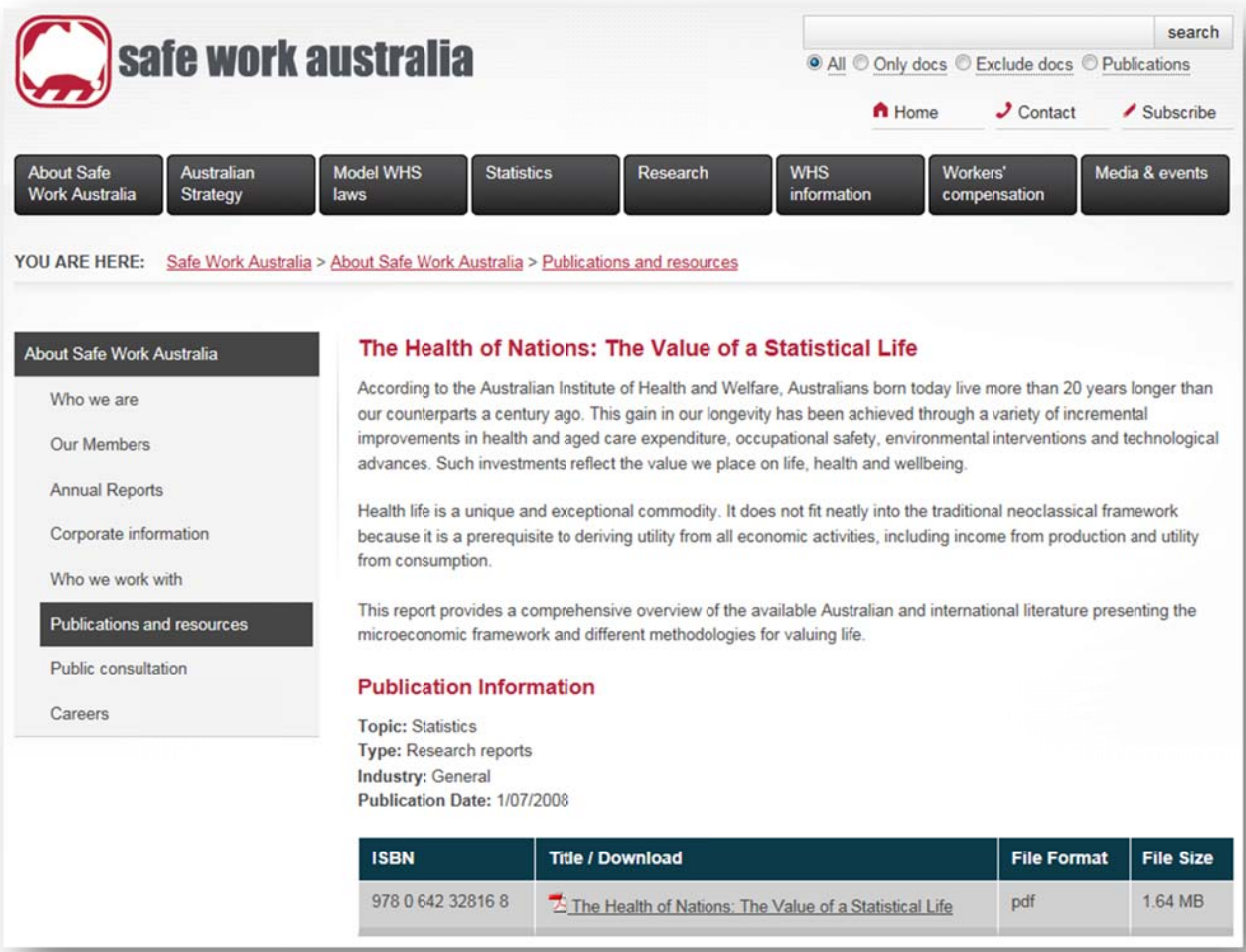
**Value of statistical life**

**Key Points:**

- Willingness to pay is the appropriate way to estimate the value of reductions in the risk of physical harm – known as the value of statistical life
- Based on international and Australian research a credible estimate of the value of statistical life is $3.5m and the value of statistical life year is $151 000
- There are complicating assumptions used to derive these estimates so a sensitivity analysis should be undertaken as part of the cost-benefit analysis

The concept is also supported by Safe Work Australia who has a link to the Government report (The Health of Nations: The Value of a Statistical Life, 2007, Australian Government – Australian Safety and

Compensation Council.) on the resources page of their website.




### 14.1.3 How to handle injuries

The government best practice regulation guidance note suggests that the VSL can be adjusted by the disability weightings published by the Australian Institute of Health and Welfare. This information is also included in the above document on the Safe Work Australia website.

A sample of data from this document is included in the table below:

| Injury | Weighting |
|---|---|
| Slipped disk with chronic pain | 0.125 |
| Burns (< 20% of body) | 0.158 |
| Thumb amputation | 0.165 |
| Long term eye injury | 0.298 |
| Leg or foot amputation | 0.300 |
| Burns (> 20% of body) | 0.441 |
| Injured spinal cord | 0.725 |

### 14.1.4 Disproportionate factor

In the Work Health and Safety sense, it is insufficient to use the VSL (or injury adjusted VSL) alone, as the WHS Act requires that the cost be ‘grossly disproportionate’ to the value for a control to be ruled out as not reasonably practicable. The HSE (UK Health & Safety Executive) is the relevant safety authority in the UK. The principles of modern risk management, including the concepts of ALARP and ‘grossly disproportionate’ are rooted in UK practice and Law. HSE refers to this disproportion as *“the bias on the side of safety”*, *“erring on the side of safety”*, and *“compensating to some extent for imprecision in the comparison of costs and the benefits”*

For a control to be deemed to be not reasonably practical, the following test should be satisfied:

Cost > Benefit x DF (disproportionate factor)

It is generally accepted that the DF lies between the extreme limits of 1 to 10, with 10 being applicable where risks are high and approach the limit of social tolerability, or where the consequences are extreme (such as multiple deaths). The DF then ramps down in some way to within the range 1 to 3 at the point where the risk becomes low or broadly acceptable to society.

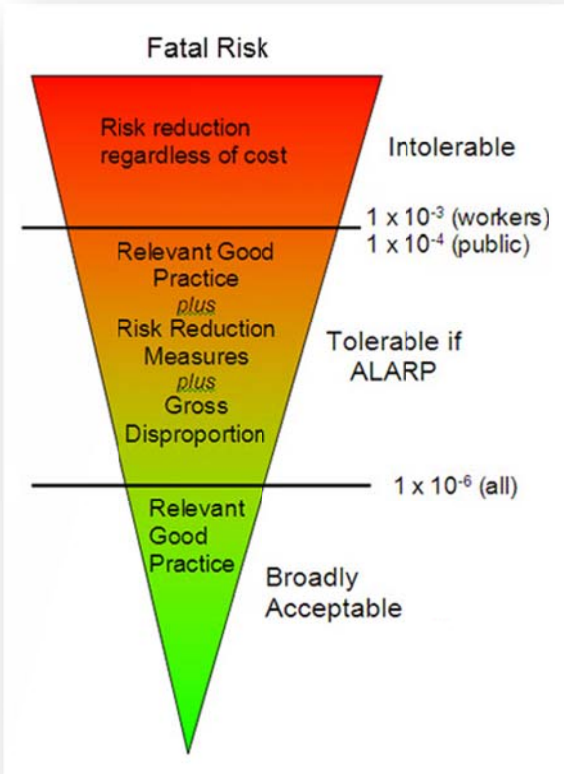
Victorian Government Guidance: *The ANCOLD (2003a) guidelines are based on HSE which indicates as generally reasonable a disproportionality factor of 10 for risks just below the Limit of Tolerability and dropping to approximately 3 for risks just above the broadly acceptable level. The HSE framework is widely used and it is appropriate that disproportionality be applied in assessing ALARP.*

### 14.1.5 Risk tolerability – individual risk

The chart on the right illustrates the basic risk tolerability criterion which has originated from the UK HSE.

Risks of fatality greater than 1 in 1,000 per person per annum for workers, or greater than 1 in 10,000 per person per annum for members of the public are considered to be intolerable and must be controlled or the activity ceased regardless of cost. To put this into perspective, these risks levels are of similar likelihood to that of the average Australian being injured or killed (respectively) in a road accident.

Safe Work Australia: *If the degree of harm is significant (e.g. death or serious injury is at least moderately likely) it is likely that the cost of available and suitable safeguards would never be so disproportionate as to justify a decision not to implement them.*




**HSE risk tolerability guidance**

It is only for low/tolerable risk levels that the ALARP principle and ‘grossly disproportionate’ test should be applied. At these limits of tolerability, a DF of 10 might be appropriate.

HSE: *“The zone between the unacceptable and broadly acceptable regions is the tolerable region. Risks in that region are typical of the risks from activities that people are prepared to tolerate in order to secure benefits”* e.g. driving a car.

In the UK model, risks below 1 in 1,000,000 per person per annum are considered to be acceptable, however Safe Work Australia has said that *“Although the broad risk ranges appear compatible with the Work Health and Safety Act performance standard of ‘so far as is reasonably practicable’, the interpretation does not incorporate the continuous improvement aspects contained within the Regulations. This means that at the lowest risk band, some risks may remain not reduced, even where it may be reasonably practicable to further reduce the risk.”* This clearly implies that risks below this level should not be discounted, and that the ALARP principle still applies.

This can also be summarised by Australian Case Law: *“Where it is possible to guard against a foreseeable risk, which, though perhaps not great, nevertheless cannot be called remote or fanciful, by adopting a means, which involved little difficulty or expense, the failure to adopt such means will in general be negligent.”* [Gibbs, Chief Justice Sir Harry. Turner v State of South Australia (1982). High Court of Australia before Gibbs CJ, Murphy, Brennan, Deane and Dawson JJ.]

Some common risk levels for context:

| Risk | Approximate individual fatal risk (average per Australian) | |
|---|---|---|
| | per person per annum | X In 1,000,000 per annum |
| 70yr old man (overall risk of death) | 1 in 35 | 28,571 |
| Seriously injured in road accident | 1 in 750 | 1,333 |
| 40yr old man (overall risk of death) | 1 in 1,000 | 1,000 |
| Fatal road accident | 1 in 15,000 | 67 |
| Accidental poisoning causing death | 1 in 22,000 | 45 |
| Assault causing death | 1 in 117,000 | 9 |

**Some common risks**

### 14.1.6 Recommended reading

HSE ALARP expert guidance – www.hse.gov.uk/risk/expert.htm

HSE document: Reducing Risks, Protecting People (R2P2) – accessible from above website.

HSE document: Good practice and pitfalls in risk assessment – report 151

### 14.1.7 Example CBA

## Example CBA from the UK Health and Safety Executive (HSE)

Source: http://www.hse.gov.uk/risk/theory/alarpcheck.htm

A simple method for coarse screening of measures is presented below. This puts the costs and benefits into a common format of '£s per year' for the lifetime of a plant.

Consider a chemical plant with a process that if it were to explode could lead to:

- 20 fatalities
- 40 permanently injured
- 100 seriously injured
- 200 slightly injured

The rate of this explosion happening has been analysed to be about 1 x $10^{-5}$ per year, which is 1 in 100,000 per year. The plant has an estimated lifetime of 25 years.

How much could the company reasonably spend to eliminate (reduce to zero) the risk from the explosion?

If the risk of explosion were to be eliminated the benefits can be assessed to be:

| | | | | | |
|---|---|---|---|---|---|
| Fatalities: | 20 | x 1,336,800 | x 1 x $10^{-5}$ | x 25 yrs | =6684 |
| Permanent injuries: | 40 | x 207,200 | x 1 x $10^{-5}$ | x 25 yrs | = 2072 |
| Serious injuries: | 100 | x 20,500 | x 1 x $10^{-5}$ | x 25 yrs | = 512 |
| Slight Injuries: | 200 | x 300 | x 1 x $10^{-5}$ | x 25 yrs | = 15 |
| Total benefits | | | | | = £9,283 |

The sum of £9,283 is the estimated benefit of eliminating the major accident explosion at the plant on the basis of avoidance of casualties. (This method does not include discounting or take account of inflation.)

For a measure to be deemed not reasonably practicable, the cost has to be grossly disproportionate to the benefits. This is taken into account by the disproportion factor (DF). In this case, the DF will reflect that the consequences of such explosions are high. A DF of more than 10 is unlikely.

Therefore it might be reasonably practicable to spend up to somewhere in the region of £93,000 (£9300 x 10) to eliminate the risk of an explosion. The duty holder would have to justify use of a smaller DF.

This type of simple analysis can be used to eliminate or include some measures by costing various alternative methods of eliminating or reducing risks.

### 14.1.8 Discounting

HSE guidance:

*"For most public policy applications, a real rate of return of 6% a year is used currently to discount costs and benefits. This assumes that all monetary costs and benefits are expressed in real terms (constant prices). The value that individuals place on safety benefits tends to increase as living standards improve,*

*so the future values applied to such benefits should be uprated to allow for the impact on well-being of expected growth in average real income. On the basis of past trends and Treasury guidance, HSE regards an uprating factor of 4% a year as appropriate on the benefits side of the comparison."*

Whilst some adjustment to these factors might be appropriate in Australia, and in this business, these factors have been used in this analysis. Adjustment is unlikely to impact on the outcome.

#### 14.1.9 The practical limit to risk reduction (and the dangers of conservatism)

Key points from research:

- There is a practical limit to safety risk reduction when direct and indirect risk transfers are considered.
- **Costly or resource intensive risk controls can increase safety risk rather than reduce it through direct and indirect risk transfers.**
- Quantitative risk assessment is necessary to ensure only effective risk controls are implemented which are cost justified and which don't increase overall risk.
- Conservatism in risk assessment is to be avoided, since it increases the likelihood of employing risk controls which increase risk rather than reduce it.

Risk control decisions made qualitatively and/or conservatively can often result in greater harm than good. The literature refers to these decisions as statistical murder.

Extract from "How safe is too safe":

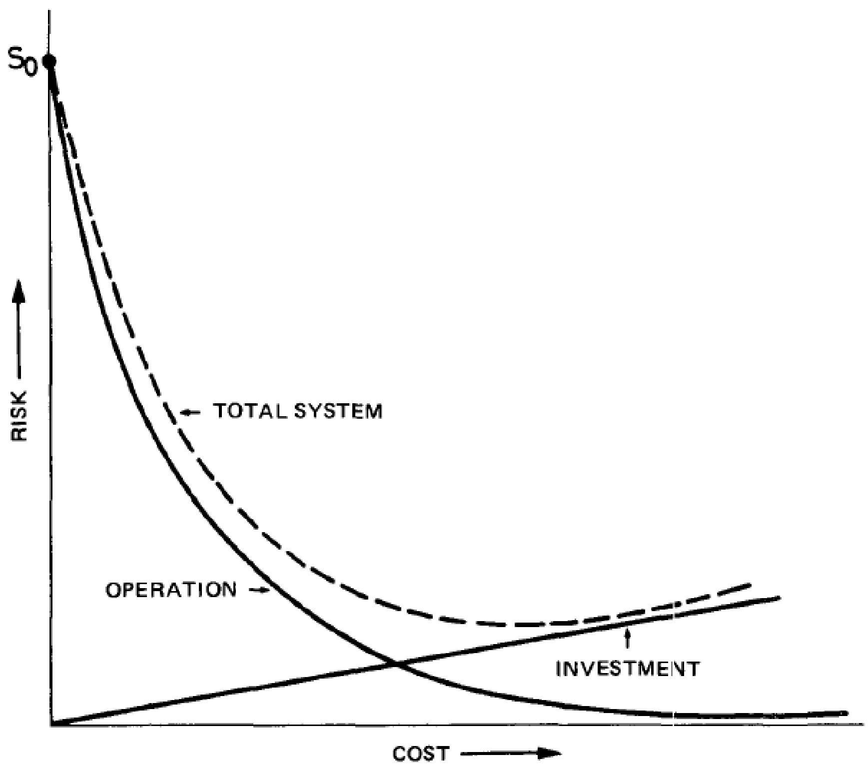



**FIGURE 2. Principal relationship of cost-effectiveness of risk reduction considering the total economic system.**

*"Decisions on safety, therefore, have to be made in such a manner as to spend the limited resources of society in a cost-effective way."*

***"These considerations are especially valid for basic services to society, such as electricity production, where expenditures that go beyond the principle of "as low as reasonably achievable" (ALARA) are directly reflected in the price of a kWh and are thus borne by every member of society."***

*"…the following will suggest that a practical limit to risk reduction does exist, because excessive expenditures for risk reduction will actually increase the total risk to society."*

Nichols says: (In "The Perils of Prudence")

*Conservatism in risk assessment, in other words, may well lead to a pattern of regulatory decisions that jeopardizes public health and safety.*

*If the purpose of using upper-bound assumptions is to provide a margin of safety in risk regulation, it is a badly flawed strategy.*

*Part of the problem with upper-bound assumptions is that even modest overestimates can easily compound to yield a substantial exaggeration of the overall risk. Each choice, when viewed in isolation, may appear plausible and prudent, but the end result can be an extreme estimate that no longer qualifies as plausible.*

*The problem is that the degree of conservatism applied at each stage accumulates multiplicatively. For example, if a risk estimate is a multiple of five (independent) factors, and risk assessors use a value for each factor just twice its expected value, their estimate will be 32 times greater than the expected risk.*

*The expected-value approach, firmly grounded in the theory of rational decision-making under uncertainty, offers several major advantages over present practice.*

The paper "Redistributing risk" says:

***…occupational risks exist, and are likely to exist whenever someone says "go make things safer".***

*At a certain point the occupational and public risk of producing safety equipment becomes higher than the reduction achieved in an existing risk. Based on data from the Federal Republic of Germany it has been estimated that 1 equivalent death or 6000 equivalent lost man-days are caused during the construction and installation of safety equipment costing about $33 million. Thus, expenditures on safety at marginal costs of risk reduction higher than $33 million per equivalent life saved would actually lead to an increase in risk. One might conclude that it had been made too" safe. Furthermore, this expenditure implies that 1400 man-years of effort [the labor that $33 million buys] per equivalent life have been used for no net gain in safety.*

*It seems ridiculous to spend $33 million ... to shift a fatality or disabling injury from one individual to another. But that is what we do when we look at risks too narrowly and apply risk criteria that are too conservative.*

***It is now understood that resources used for risk control are unavailable for other social purposes. It is less often appreciated that the public health is sensitive to income and economic growth. In our risk analyses we account for the direct health benefits that risk-reducing investments provide, but we do not generally consider the health benefits that would occur if these resources were simply used to increase per capita income. Yet the links between economic well-being and health have long been known, even if the mechanisms that drive this relation (medical care, diet, shelter, and other material standards) are not fully understood by expert observers.***

*__As we have seen, safety requirements often shift risks to workers who make safety equipment. It is also clear that safety investments use resources that would otherwise be used to increase income, and that even small income changes are associated with health changes that may be larger than the risks of concern.__ While it may be politically attractive in some quarters to portray our industrial economy as sustained only by the toleration of large public or occupational hazards, the evidence is that in the aggregate economic growth extends life.*

*__Just as it is no longer acceptable for industry to ignore externalities, it is equally inappropriate for risk managers, including regulators, judges, doctors, and others, to ignore the consequences of their actions. Under narrowly considered risk decisions, risk transfers are a type of externality.__ One means of detecting and perhaps reducing the incidence of unanticipated risk transfers is for risk and policy analysts to be aware of the systemic factors, described here, that frequently give rise to these effects. Full disclosure of transfers by risk assessors and regulators should be the goal; and, wherever legally feasible, a net risk point of view should be taken in interpreting congressional intent in risk legislation.*

*As examples given here have indicated, __some decisions not to regulate a small risk can be defended on risk grounds alone.__ When this is possible, the regulator avoids the complex value-based arguments familiar in cost-benefit debates.*

*Regulators should also take care to understand that traditional practices that tempt them to put their thumb on one side of the risk scales, such as the tendency to overemphasize distinctions between old and new risk or natural and man-made risk, will generally lead to greater loss of life than will policies that are insensitive to the origin of the risk. Our values toward risk need not be neutral in these and other qualitative dimensions, but we should understand that aversion to risks with undesirable qualities can lead to risk-increasing transfers. This happens when people who are afraid to fly travel by automobile.*

*Likewise, __one frequently encounters the attitude that "conservatism" in the analysis of uncertain risks is the best way to protect the public. But this is not true when risk transfers are likely.__ Adopting "worst-case" assumptions about a substance or technology can amount in practice to adopting "best-case" assumptions about a substitute that may in fact be worse. At the very least, such an approach diverts resources from more beneficial ends.*

*Finally, __a degree of modesty would be welcome in targeting small risks involving complex processes where unknown risk transfers can easily swamp the intended result. Two major sources of risk transfer-occupational risk transfer and the risk effects of slowing down economic growth-are apparently of special importance in the case of small, diffuse risks that are expensive to eliminate.__ Indeed, it may be that case-by-case elimination of small risks not only is less cost-effective in health terms than are measures to improve economic growth, but at times actually can conflict with those measures.*

*Looking for risk transfers would appear, at first glance, to further complicate the already complicated business of risk regulation, increasing the analytical burdens on agency staff and policy makers. But the stakes involved are high enough to make it worthwhile. When we recognize that it is often difficult to bring about a net risk reduction, let alone an improvement in social well-being, we will be better able to deal with the risks we face.*

Rethinking Risk and the precautionary principle (Book, 2000, Julian Morris)

*The most seductive form of playing it safe is prudential conservatism. Why be half safe? When in doubt, add margins of safety. Allow nothing new unless pre-guaranteed as harmless. Such fields as toxicology and engineering present honourable examples of conservatism. … Safety margins will be increased on* *‘worst-case’ considerations, and then again on the grounds that it doesn’t hurt to be even more careful. … As uncertainties are resolved by exaggeration, estimates of potential damage also may be increased thousands of times over. So what? Is there anything wrong with being super cautious? Conservatism can be pursued to infinity and since virtually everything contains some harm, the inescapable conclusion is to decide the activity should be disallowed altogether.*

*There is an essential difference between calculating a risk carefully and then deliberately choosing a conservative design in such a way as to reduce the risk to a desired level, and deliberately erring in a conservative direction in the calculation of risk. An error in the conservative direction is nonetheless an error.*

*The imposition of safety factors is sensible, but only if two considerations are observed: first, the best known probabilities are calculated and then the adverse effects of increasing the margin of error are taken into account.*

Investments in Fire Management: Does saving lives cost lives? (2012, Brian Ashe)

*‘Death’ by regulation:*

*Over the past 25 years, the number of government regulations aimed at improving safety in both Europe and America has soared (Economist 2004). John Graham, appointed as America’s top regulator at the Office of Management and Budget in 2001, was previously an academic who promoted the use of cost–benefit methodologies to analyse risks. He called the inefficiencies of regulation ‘statistical murder’, arguing that bad regulation absorbs money that could be better spent to save lives another way (ibid).*

*He argued that economic growth, not government regulation, has been the primary means by which life expectancy and health status have improved, and that government policies formulated without taking into account the scarcity of resources may often do more harm than good.*

*Lutter and Morrall (1994) used the notion of a utility maximising individual to derive a general relationship between the* ***critical income loss necessary to induce one fatality. They refer to this as society’s willingness to spend (WTS)*** *to reduce health-and-safety risks and determined its value for a number of countries.* ***In the case of Australia, they estimated the WTS as US$4.2 million in 1980 dollars. Adjusting this figure for changes in Gross Domestic Product (GDP), the current Australian WTS would be around about A$15 million in 2010 dollars.***

*In the most recent work in this field, Gerdtham and Johannesson (2002) also concluded that life-saving regulations/interventions may be counterproductive if they have an indirect mortality effect through the reduction in disposable income. The income loss that will induce one ‘statistical’ or ‘regulatory’ fatality in Sweden was estimated to be US$6.8 million when costs were borne equally among all adults.*

*The manner in which regulatory costs are allocated among individuals depends on the complex workings of the economy and the intermediaries and thus may be borne very differentially (Lutter and Morrall 1994). Here, two possibilities are separately considered: first, where all costs are shared equally among individuals regardless of income; and secondly, where costs are imposed proportional to the individual’s income. Since no studies have been undertaken to determine which premise is most appropriate for Australia, the following discussion considers both.* ***When regulatory costs are shared proportional to income, we find that the WTS is A$50 million, and when costs are shared equally among the whole of the Australian population, the WTS reduces to A$20 million.***

*By way of comparison, Lutter and Morrall (1994) estimated a corresponding figure of US$4.2 million in 1980 dollars, which equates to approximately A$15 million in 2010 terms. While broad agreement with the lower value from the Keeney (1997) model is comforting, given the uncertainties in its calculation, in what follows we shall employ the WTS range of A$20–50 million.*

The real cost of fire in Australia (World fire statistics bulletin Oct 2012, Ashe) [link]

*Australia's fire fatality rate of 0.6 per 100,000 of population, already low by international standards, has proved resistant to increasing expenditure on fire management and protection. Following a concern that this expenditure might encompass a significant over-investment compared with the real risk, we then examined the regulatory cost of this investment, costs that are ultimately borne by individuals via taxes and/or higher prices for goods and services. Further, since poorer people on average have poorer health outcomes, it is possible this regulatory cost increases mortality. Adapting a model of Keeney3 for the U.S. to Australian conditions, we determine the "regulatory" cost of a fatality to be between AU$20 and AU$50 million. The range reflects alternative ways in which these costs are distributed over the population.* ***If we accept the results of an expert elicitation to imply an over-investment in fire prevention and management of AU$2 billion, this excess is equivalent to between 40 and 100 statistical fatalities annually, figures that are of the same order as the annual number of actual fire fatalities (~114). While there is no correct answer to how much taxpayers' money should be devoted to protecting citizens from the threat of fire, it does seem as if the current system is over-indulgent.*** *The methodology proposed here for fire risk is easily adapted to other areas of government investment and its consideration would ensure that there is some balance between government investments and desired outcomes.*

The cost of fire in Australia (Risk Frontiers, Macquarie University)

*The Bureau of Transport and Regional Economics in their study into rail accident costs in Australia concluded that the average economic cost of a fatality was around AUD$1.9 million in 2002. In his earlier report into the economic costs of Natural Disasters in Australia, Slatyer(26) estimated the average cost to be AUD$1.3 million in 2001 dollars per fatality. Considering these studies(14)(26), an estimate of AUD$ 2 million is assumed to be the current cost of a fatality in Australia. Given the average annual fire-related fatality numbers for Australia (97 taken from the 'Report on Government Services'(1)), this equates to a cost of AUD $194 million.*

*The results also show that Australia is investing approximately AUD$7,200 million (or 85% of the total cost of fire) to manage a loss of approximately AUD$1,300 million (or 15% of the total cost of fire), a result that raises questions as to the most effective and efficient investment of approximately AUD$420 for every Australian.*

*http://www.theland.com.au/news/agriculture/agribusiness/general-news/money-wasted-on-fire-prevention/2643280.aspx*

*He said that if $4.5 billion of the money spent on fire safety was instead returned to businesses and consumers as tax cuts, health and nutrition would improve. His modelling suggests such a tax cut would save between 90 and 225 lives a year. About 114 lives are lost each year from fire - 14 of them from bushfires.*

# 15.0 APPENDIX H (REFERENCES)

## 15.1 References – Electrical safety


***Arc Flash Hazard Standards, The Burning Question***, 2010, Sesha Prasad, Paper presented at IDC Electrical Arc Flash Forum, Melbourne 2010

***Burns***, Wikipedia, viewed 5 Sept 2013,

***Electrical Injuries in Emergency Medicine Clinical Presentation***, 2013, Medscape

***Electrical Safety Handbook***, 2006, McGraw Hill, Cadick J., etal, ISBN 0-07-158912-0

***Electrical Safety Hazards Handbook***, 2005, Littlefuse

***Guide for the Management of Arc Flash Hazards***, October 2011, EEA (Electricity Engineers' Association)

***The fatal current***, Ohio state University, Physics department


## 15.2 References – Bushfire risk


***2009 Victorian Bushfires Royal Commission Final Report Summary***, July 2010, Parliament of Victoria

***Bushfires in NSW: timelines and key sources, NSW Parliament Issues Backgrounder***, NSW Parlimentary Research Service, No6, June 2014,

***Environmental circumstances surrounding bushfire fatalities in Australia in 1901-2011***, Environmental Science & Policy 37 (2014), p192-203, R Blanchi, etal,

***Investments in Fire Management: Does saving lives cost lives?***, 2012, Brian Ashe

***Powerline Bushfire Safety Taskforce: Final Report***, 2011, Powerline Bushfire Safety Taskforce


## 15.3 References – Risk & other


***Acceptable Risk*** *(Article)*, Professional Safety Magazine, May 2010, American Society of Safety Engineers,

***ALARP*** *(As low as reasonably practical*, Jakeman Business Solutions, viewed 23 Aug 2013

***ALARP Evaluation: Using cost effectiveness and disproportionality to justify risk reduction***, 2002, Bowles D, ANCOLD 2002 Conference

***ALARP – Expert guidance***, UK Health and Safety Executive

***ALARP Guidance Note***, NOPSEMA (Australian offshore industry regulator), December 2012

***Back to Basics: Risk Matrices and ALARP***, 2009, David R., Wilkinson G.

***Cost Benefit Analysis Methodology Procedures Manual***, Ver1.0, 2007, Civil Aviation Safety Authority (Australia)

***Dam safety, economic regulation and society's need to prioritise health and safety expenditures***, 2007, Marsden J, etal

***Establishing a Monetary Value for Lives Saved: Issues and Controversies***, 2008, Dr Peter Abelson

***Guide for Major Hazard Facilities*** *(Safety Case: Demonstrating the adequacy of safety management and control measures)*, March 2012, Safe Work Australia, (p24-28)

***Guidance Note on Dam Safety Principles***, May 2012, Victorian Government Department of Sustainability and Environment Melbourne, ISBN 978-1-74287-510-1

***Good practice and pitfalls in risk assessment*** - *Research Report 151*, 2003, (UK) HSE, Gadd G., etal

***How to determine what is Reasonably Practical to meet a Health & Safety Duty***, May 2013, Safe Work Australia, ISBN 978-1-74361-065-7

***Handbook of Cost-Benefit Analysis***, January 2006, Australian Government - Department of Finance and Administration

***HSE: Good practice and pitfalls in risk assessment***, 2003

***HSE: Guidance on 'As low as reasonably practicable' (ALARP) decisions in control of major accident hazards (COMAH)***, UK HSE

***HSE: Guidance on Risk Assessment for Offshore Installations***, 2006, HSE Information Sheet

***HSE: Principles and guidelines to assist HSE in its judgements that duty-holders have reduced risk as low as reasonably practicable***, HSE website 2013

***Occupational Risk Control: Predicting and Preventing the Unwanted***, D Viner, 2015, Gower Publishing Ltd, ISBN 9781472419712

***Reducing Risks, Protecting People – HSE's decision-making process***, UK Health & Safety Executive, 2001

***Requirements for Demonstration (Major Hazard Facilities)***, April 2011, Work Safe Victoria

***Safety at Any Price?***, 2002, Viscusi W, Gayer T, Regulation Magazine Fall 2002

***The Health of Nations: The Value of a Statistical Life***, 2007, Australian Government – Australian Safety and Compensation Council

***The Societal Aspects of Risk***, Royal Academy of Engineering

***Tolerable Risk***, September 2007, Chemical Engineering Magazine

***Value of Statistical life – best practice guidance note***, Australian Government – Office of Best Practice Regulation, viewed 23 Aug 2013

***Reducing Trauma as a result of crashes involving utility poles***, RTA – NSW Centre for Road Safety, August 2009

[1] http://www.pgecurrents.com/2012/06/20/pge-research-leads-to-better-protection-for-workers-from-arc-flashes/300x200_arc_flash/

[2] http://www.ebranders.com/showcase_electrical_safety_authority_arc_flash.html

[3] http://www.propumpservice.com/safety_graphic_photos.php

[4] http://www.arcflash.com.au/

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# APPENDIX B - COST ESTIMATE

Refer to the attached Appendix B – Cost estimate

| Zone Sub | Type | Feeder | Relay | Cost for OCEF Relay Installation, $ | | | | | | Core Balance CTs Added, $ | | | | Cost for CBF for Fdrs Not Included in Project, $ | Cost for LAN , $ | Additional Cost for feeder Double-ups, $ | TOTAL, $ Excl. CPI | Cost Per Site, $ | Cost Per Feeder, $ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Panel, Hardware and Relays | Design and Tech | DC Config., Site Preparation, Per Site | Project Mgt | Asbestos Mgt, $ | **TOTAL Excl. CPI** | Cost for Core Bal CT | Cost associated with Pitch Filled Cable Boxes | | **TOTAL WITH CORE BAL CTs** | | | | | | |
| | | | | | | | | | | | STJ | Air Box | | | | | | | |
| APPIN | A | W111 (1 + Aux) | GEC CDG | 6,150 | 17,500 | 24,500 | 5,180 | | 53,330 | 3,000 | - | - | 56,330 | 2,500 | 24,770 | | **83,600** | 170,450 | 42,613 |
| APPIN | A | W112 | GEC CDG | 6,150 | 17,500 | | 2,300 | | 25,950 | 3,000 | - | - | 28,950 | | | | **28,950** | | |
| APPIN | A | W113 | GEC CDG | 6,150 | 17,500 | | 2,300 | | 25,950 | 3,000 | - | - | 28,950 | | | | **28,950** | | |
| APPIN | A | W114 | GEC CDG | 6,150 | 17,500 | | 2,300 | | 25,950 | 3,000 | - | - | 28,950 | | | | **28,950** | | |
| PORTLAND | A | T838 | GEC CDG | 6,150 | 17,500 | 24,500 | 4,380 | | 52,530 | | - | - | 52,530 | 10,000 | 30,770 | | **93,300** | 143,600 | 47,867 |
| PORTLAND | A | T841 (1 + Aux) | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| PORTLAND | A | T842 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| MOOREBANK | D | 6419 (2 fdrs) | GEC CDG | 8,850 | 17,500 | 24,500 | 4,380 | | 55,230 | | - | - | 55,230 | 15,000 | 36,770 | 37,300 | **144,300** | 460,950 | 38,413 |
| MOOREBANK | A | 6420 (1+Cap) | Basler 851 and 2C138 (5A) | 6,150 | 17,500 | | 1,500 | | 25,150 | - | - | - | 25,150 | | | | **25,150** | | |
| MOOREBANK | A | 6423 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| MOOREBANK | A | 6426 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| MOOREBANK | A | 6427 (2 cables) | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| MOOREBANK | A | 6429 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| MOOREBANK | A | 6430 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| MOOREBANK | A | 6431 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| MOOREBANK | D | B743 (2 Fdrs) | GEC CDG | 8,850 | 17,500 | | 1,500 | | 27,850 | | - | - | 27,850 | | | 37,300 | **65,150** | | |
| MOOREBANK | A | B745 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| MOOREBANK | A | B746 (1 + Cap) | Basler 851 and 2C138 (5A) | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| MOOREBANK | A | B747 (1 + Aux) | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| PORT CENTRAL | C | PCA2 | GEC CDG | 6,150 | 17,500 | 24,500 | 4,380 | 3,000 | 55,530 | | - | - | 55,530 | 7,500 | 30,770 | | **93,800** | 234,550 | 39,092 |
| PORT CENTRAL | C | PCB2 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| PORT CENTRAL | C | PCC2 (1 + Cap) | Basler 851 and 2C138 (5A) | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| PORT CENTRAL | C | PCD2 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| PORT CENTRAL | C | PCE2 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| PORT CENTRAL | C | PCF2 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| SEVEN HILLS | A | 8610 | GEC CDG | 6,150 | 17,500 | 24,500 | 4,380 | | 52,530 | - | - | - | 52,530 | 12,500 | 33,770 | | **98,800** | 345,800 | 24,700 |
| SEVEN HILLS | | | | | 17,500 | | 1,500 | | 19,000 | - | - | - | 19,000 | | | | **19,000** | | |
| SEVEN HILLS | | | | | 17,500 | | 1,500 | | 19,000 | - | - | - | 19,000 | | | | **19,000** | | |
| SEVEN HILLS | | | | | 17,500 | | 1,500 | | 19,000 | - | - | - | 19,000 | | | | **19,000** | | |
| SEVEN HILLS | | | | | 17,500 | | 1,500 | | 19,000 | - | - | - | 19,000 | | | | **19,000** | | |
| SEVEN HILLS | | | | | 17,500 | | 1,500 | | 19,000 | - | - | - | 19,000 | | | | **19,000** | | |
| SEVEN HILLS | | | | | 17,500 | | 1,500 | | 19,000 | - | - | - | 19,000 | | | | **19,000** | | |
| SEVEN HILLS | | | | | 17,500 | | 1,500 | | 19,000 | - | - | - | 19,000 | | | | **19,000** | | |
| SEVEN HILLS | | | | | 17,500 | | 1,500 | | 19,000 | - | - | - | 19,000 | | | | **19,000** | | |
| SEVEN HILLS | | | | | 17,500 | | 1,500 | | 19,000 | - | - | - | 19,000 | | | | **19,000** | | |
| SEVEN HILLS | | | | | 17,500 | | 1,500 | | 19,000 | - | - | - | 19,000 | | | | **19,000** | | |
| SEVEN HILLS | | | | | 17,500 | | 1,500 | | 19,000 | | - | - | 19,000 | | | | **19,000** | | |
| SEVEN HILLS | | | | | 17,500 | | 1,500 | | 19,000 | | - | - | 19,000 | | | | **19,000** | | |
| SEVEN HILLS | | | | | 17,500 | | 1,500 | | 19,000 | | - | - | 19,000 | | | | **19,000** | | |
| HORSLEY PARK | A | 8711 (1 + Aux) | GEC CDG | 6,150 | 17,500 | 24,500 | 4,380 | 3,000 | 55,530 | | - | - | 55,530 | 10,000 | 30,770 | | **96,300** | | |
| HORSLEY PARK | A | 8712 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| HORSLEY PARK | A | 8714 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| HORSLEY PARK | A | 8715 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | 35,722 |

| Zone Sub | Type | Feeder | Relay | Cost for OCEF Relay Installation, $ | | | | | | Core Balance CTs Added, $ | | | | Cost for CBF for Fdrs Not Included in Project, $ | Cost for LAN , $ | Additional Cost for feeder Double-ups, $ | **TOTAL, $ Excl. CPI** | **Cost Per Site, $** | **Cost Per Feeder, $** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Panel, Hardware and Relays | Design and Tech | DC Config., Site Preparation, Per Site | Project Mgt | Asbestos Mgt, $ | **TOTAL Excl. CPI** | Cost for Core Bal CT | Cost associated with Pitch Filled Cable Boxes | | **TOTAL WITH CORE BAL CTs** | | | | | | |
| | | | | | | | | | | | STJ | Air Box | | | | | | | |
| HORSLEY PARK | A | 8716 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | 321,500 | |
| HORSLEY PARK | A | 8718 (1 + Aux) | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| HORSLEY PARK | A | 8719 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| HORSLEY PARK | A | 8721 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| HORSLEY PARK | A | 8722 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| GLOSSODIA | A | L941 | GEC CDG | 6,150 | 16,220 | 24,500 | 5,180 | | 52,050 | 3,000 | 5,000 | - | 60,050 | 7,500 | 30,770 | | **98,320** | 279,510 | 46,585 |
| GLOSSODIA | A | L947 | GEC CDG | 6,150 | 17,500 | | 2,300 | | 25,950 | 3,000 | 5,000 | - | 33,950 | | | | **33,950** | | |
| GLOSSODIA | A | L948 | GEC CDG | 6,150 | 17,500 | | 2,300 | | 25,950 | 3,000 | 5,000 | - | 33,950 | | | | **33,950** | | |
| GLOSSODIA | A | L940 | GEC CDG | 6,150 | 16,220 | | 2,300 | | 24,670 | 3,000 | 5,000 | - | 32,670 | | | | **32,670** | | |
| GLOSSODIA | A | L942 (1 + Aux) | GEC CDG | 6,150 | 16,220 | | 2,300 | | 24,670 | 5,000 | 10,000 | - | 39,670 | | | | **39,670** | | |
| GLOSSODIA | A | L946 (1 +Aux) | GEC CDG | 6,150 | 17,500 | | 2,300 | | 25,950 | 5,000 | 10,000 | - | 40,950 | | | | **40,950** | | |
| LUDDENHAM | A | A096 (1 +Aux) | GEC CDG | 6,150 | 17,500 | 24,500 | 5,180 | 3,000 | 56,330 | 5,000 | - | 15,500 | 76,830 | 7,500 | 30,770 | | **115,100** | 252,450 | 63,113 |
| LUDDENHAM | A | A095 | GEC CDG | 6,150 | 17,500 | | 2,300 | 3,000 | 28,950 | 3,000 | - | 12,000 | 43,950 | | | | **43,950** | | |
| LUDDENHAM | A | A098 (1 +Aux) | GEC CDG | 6,150 | 17,500 | | 2,300 | 3,000 | 28,950 | 5,000 | - | 15,500 | 49,450 | | | | **49,450** | | |
| LUDDENHAM | A | A099 | GEC CDG | 6,150 | 17,500 | | 2,300 | 3,000 | 28,950 | 3,000 | - | 12,000 | 43,950 | | | | **43,950** | | |
| SHERWOOD | A | 9046 | GEC CDG | 6,150 | 17,500 | 24,500 | 4,380 | 3,000 | 55,530 | - | - | - | 55,530 | 20,000 | 36,770 | | **112,300** | 421,950 | 35,163 |
| SHERWOOD | A | 9047 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | - | - | - | 28,150 | | | | **28,150** | | |
| SHERWOOD | A | 9049 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | - | - | - | 28,150 | | | | **28,150** | | |
| SHERWOOD | A | 9050 (1 + Aux) | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | - | - | - | 28,150 | | | | **28,150** | | |
| SHERWOOD | A | 9052 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | - | - | - | 28,150 | | | | **28,150** | | |
| SHERWOOD | A | 9053 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | - | - | - | 28,150 | | | | **28,150** | | |
| SHERWOOD | A | 9055 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | - | - | - | 28,150 | | | | **28,150** | | |
| SHERWOOD | A | 9056 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | - | - | - | 28,150 | | | | **28,150** | | |
| SHERWOOD | A | 9057 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | - | - | - | 28,150 | | | | **28,150** | | |
| SHERWOOD | A | 9059 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | - | - | - | 28,150 | | | | **28,150** | | |
| SHERWOOD | A | 9060 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | - | - | - | 28,150 | | | | **28,150** | | |
| SHERWOOD | A | 9062 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | - | - | - | 28,150 | | | | **28,150** | | |
| NORTH ROCKS | A | 8734 | GEC CDG | 6,150 | 17,500 | 24,500 | 4,380 | 3,000 | 55,530 | | - | - | 55,530 | 12,500 | 30,770 | | **98,800** | 324,000 | 36,000 |
| NORTH ROCKS | A | 8735 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| NORTH ROCKS | A | 8737 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| NORTH ROCKS | A | 8738 (1 + Aux) | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| NORTH ROCKS | A | 8740 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| NORTH ROCKS | A | 8741 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| NORTH ROCKS | A | 8743 (1 + Aux) | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| NORTH ROCKS | A | 8744 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| NORTH ROCKS | A | 8745 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| PROSPECT | A | B201 | GEC CDG | 6,150 | 17,500 | 24,500 | 4,380 | 3,000 | 55,530 | | - | - | 55,530 | 22,500 | 36,770 | | **114,800** | 396,300 | 36,027 |
| PROSPECT | A | B202 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| PROSPECT | A | B204 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| PROSPECT | A | B205 (1 + Aux) | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| PROSPECT | A | B207 (1 + Aux) | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| PROSPECT | A | B210 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| PROSPECT | A | B211 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |

| Zone Sub | Type | Feeder | Relay | **Cost for OCEF Relay Installation, $** | | | | | | **Core Balance CTs Added, $** | | | | Cost for CBF for Fdrs Not Included in Project, $ | Cost for LAN , $ | Additional Cost for feeder Double-ups, $ | **TOTAL, $ Excl. CPI** | **Cost Per Site, $** | **Cost Per Feeder, $** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Panel, Hardware and Relays | Design and Tech | DC Config., Site Preparation, Per Site | Project Mgt | Asbestos Mgt, $ | **TOTAL Excl. CPI** | Cost for Core Bal CT | Cost associated with Pitch Filled Cable Boxes | | **TOTAL WITH CORE BAL CTs** | | | | | | |
| | | | | | | | | | | | STJ | Air Box | | | | | | | |
| PROSPECT | A | B212 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| PROSPECT | A | B214 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| PROSPECT | A | B215 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| PROSPECT | A | B217 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| LENNOX | A | B773 | GEC CDG | 6,150 | 17,500 | 24,500 | 4,380 | | 52,530 | | - | - | 52,530 | 17,500 | 30,770 | | **100,800** | 402,600 | 30,969 |
| LENNOX | A | B775 (1 + Aux) | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| LENNOX | A | B776 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| LENNOX | A | B778 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| LENNOX | A | L505 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| LENNOX | A | L506 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| LENNOX | A | L507 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| LENNOX | A | L508 (1 + Cap) | | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| LENNOX | A | B777 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| LENNOX | A | L857 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| LENNOX | A | 19868 | GEC KCGG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| LENNOX | A | 19870 | GEC KCGG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| LENNOX | A | 19871 | GEC KCGG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| CABRAMATTA | A | A337 | GEC CDG | 6,150 | 17,500 | 24,500 | 4,380 | 3,000 | 55,530 | | - | - | 55,530 | 20,000 | 33,770 | | **109,300** | 390,800 | 35,527 |
| CABRAMATTA | A | A339 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| CABRAMATTA | A | A341 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| CABRAMATTA | A | A343 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| CABRAMATTA | A | A344 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| CABRAMATTA | A | A346 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| CABRAMATTA | A | A347 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| CABRAMATTA | A | A348 (1 + Aux) | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| CABRAMATTA | A | A350 (1 + Aux) | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| CABRAMATTA | A | A352 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| CABRAMATTA | A | A354 | GEC CDG | 6,150 | 17,500 | | 1,500 | 3,000 | 28,150 | | - | - | 28,150 | | | | **28,150** | | |
| WOODPARK | A | M159 | GEC CDG | 6,150 | 17,500 | 24,500 | 4,380 | | 52,530 | | - | - | 52,530 | 7,500 | 30,770 | | **90,800** | 316,500 | 35,167 |
| WOODPARK | A | M160 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| WOODPARK | A | M162 (1 + Aux) | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| WOODPARK | A | M163 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| WOODPARK | A | M165 (1 + Aux) | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| WOODPARK | A | M166 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| WOODPARK | A | M168 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| WOODPARK | A | M169 (1 + Cap) | Basler - CMUR | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| WOODPARK | D | M170 (2 Fdrs) | GEC CDG | 8,850 | 17,500 | | 1,500 | | 27,850 | | - | - | 27,850 | | | 21,800 | **49,650** | | |
| KENNY STREET | A | KYG2 | Nilsen ITP | 6,150 | 17,500 | 24,500 | 4,380 | | 52,530 | | - | - | 52,530 | 10,000 | 36,770 | | **99,300** | 275,350 | 34,419 |
| KENNY STREET | A | KYA2 | Nilsen ITP | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| KENNY STREET | A | KYB2 | Nilsen ITP | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| KENNY STREET | A | KYC2 | Nilsen ITP | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| KENNY STREET | A | KYD2 | Nilsen ITP | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| KENNY STREET | A | KYE2 (1 + Aux) | Nilsen ITP | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |

| Zone Sub | Type | Feeder | Relay | Cost for OCEF Relay Installation, $ | | | | | | Core Balance CTs Added, $ | | | | Cost for CBF for Fdrs Not Included in Project, $ | Cost for LAN , $ | Additional Cost for feeder Double-ups, $ | **TOTAL, $ Excl. CPI** | **Cost Per Site, $** | **Cost Per Feeder, $** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Panel, Hardware and Relays | Design and Tech | DC Config., Site Preparation, Per Site | Project Mgt | Asbestos Mgt, $ | **TOTAL Excl. CPI** | Cost for Core Bal CT | Cost associated with Pitch Filled Cable Boxes: STJ | Cost associated with Pitch Filled Cable Boxes: Air Box | **TOTAL WITH CORE BAL CTs** | | | | | | |
| KENNY STREET | A | KYF2 | Nilsen ITP | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| KENNY STREET | A | KYH2 | Nilsen ITP | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| INNER HARBOUR | A | IHJ2 | GEC CDG | 6,150 | 16,220 | 16,500 | 4,380 | | 43,250 | - | - | - | 43,250 | 20,000 | 36,770 | | **100,020** | 314,850 | 31,485 |
| INNER HARBOUR | A | IHE2 | GEC CDG | 6,150 | 16,220 | | 1,500 | | 23,870 | - | - | - | 23,870 | | | | **23,870** | | |
| INNER HARBOUR | A | IHF2 | GEC CDG | 6,150 | 16,220 | | 1,500 | | 23,870 | - | - | - | 23,870 | | | | **23,870** | | |
| INNER HARBOUR | A | IHH2 | GEC CDG | 6,150 | 16,220 | | 1,500 | | 23,870 | - | - | - | 23,870 | | | | **23,870** | | |
| INNER HARBOUR | A | IHD2 | GEC CDG | 6,150 | 16,220 | | 1,500 | | 23,870 | - | - | - | 23,870 | | | | **23,870** | | |
| INNER HARBOUR | A | IHK2 | GEC CDG | 6,150 | 16,220 | | 1,500 | | 23,870 | - | - | - | 23,870 | | | | **23,870** | | |
| INNER HARBOUR | A | IHL2 | GEC CDG | 6,150 | 16,220 | | 1,500 | | 23,870 | - | - | - | 23,870 | | | | **23,870** | | |
| INNER HARBOUR | A | IHM2 | GEC CDG | 6,150 | 16,220 | | 1,500 | | 23,870 | - | - | - | 23,870 | | | | **23,870** | | |
| INNER HARBOUR | A | IHC2 | GEC CDG | 6,150 | 16,220 | | 1,500 | | 23,870 | - | - | - | 23,870 | | | | **23,870** | | |
| INNER HARBOUR | A | IHB2 | GEC CDG | 6,150 | 16,220 | | 1,500 | | 23,870 | - | - | - | 23,870 | | | | **23,870** | | |
| GREYSTANES | A | 7962 | GEC CDG | 6,150 | 17,500 | 24,500 | 4,380 | | 52,530 | | - | - | 52,530 | 20,000 | 36,770 | | **109,300** | 385,950 | 32,163 |
| GREYSTANES | A | 7964 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| GREYSTANES | A | 7966 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| GREYSTANES | A | 7967 (1 + Aux) | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| GREYSTANES | A | 7970 (1 + Aux) | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| GREYSTANES | A | 7972 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| GREYSTANES | A | 7973 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| GREYSTANES | A | 7974 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| GREYSTANES | A | 7976 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| GREYSTANES | A | 7977 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| GREYSTANES | A | 7979 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| GREYSTANES | A | 7981 | GEC CDG | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| BERRIMA JUNCTION | A | BJ1255 | GEC MCGG | 6,150 | 17,500 | 24,500 | 4,380 | | 52,530 | | - | - | 52,530 | 12,500 | 24,770 | | **89,800** | 89,800 | 89,800 |
| BLACKMANS FLAT | A | T834 | | 6,150 | 17,500 | 24,500 | 4,380 | | 52,530 | | - | - | 52,530 | 7,500 | 30,770 | | **90,800** | 191,400 | 63,800 |
| BLACKMANS FLAT | A | T831 | | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| BLACKMANS FLAT | A | T828 | | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| BLACKMANS FLAT | A | T829 | | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |
| BLACKMANS FLAT | A | T836 | | 6,150 | 17,500 | | 1,500 | | 25,150 | | - | - | 25,150 | | | | **25,150** | | |

## **Cost Estimate**

| Substation | No of Relays | 2018/19 | 2019/20 | Total |
|---|---|---|---|---|
| Portland | 3 | 143,600 | | |
| Inner harbour | 10 | 314,850 | | |
| Kenny Street | 8 | 275,350 | | |
| Moorebank | 12 | 460,950 | | |
| Berrima Junction | 1 | 89,800 | | |
| Seven Hills | 14 | 425,750 | | |
| Lennox | 13 | 402,600 | | |
| Horsley Park | 9 | 321,500 | | |
| Blackmans Flat | 5 | 191,400 | | |
| Port Central | 6 | 234,550 | | |
| Appin | 4 | 170,450 | | |
| Cabramatta | 11 | 390,800 | | |
| Prospect | 11 | 396,300 | | |
| Sherwood | 12 | | 421,950 | |
| Woodpark | 9 | | 316,500 | |
| North Rocks | 9 | | 324,000 | |
| Luddenham | 4 | | 252,450 | |
| Greystanes | 12 | | 385,950 | |
| Glossodia | 6 | | 279,510 | |
| Total (real) | 159 | 3,820,000 | 1,980,000 | **5,800,000** |
| total (Nominal) | | 3,920,000 | 2,080,000 | **6,000,000** |
| Overhead (%) | | 27.70% | 24.70% | |
| Overheads | | 1,085,840 | 513,760 | **1,600,000** |
| Total | | 5,005,840 | 2,593,760 | **7,600,000** |
| Contingency | | | | **600,000** |
| **total (including contingency)** | | | | **6,600,000** |
| **total (including contingency + overheads)** | | | | |

## <u>Contingency</u>

| | |
|---|---|
| <u>Unforeseen site conditions</u> | |
| 16K per site | **304,000** |
| | |
| <u>For sites where relays are installed in separate remote P & C panels</u> | |
| 10 sites x 2wks addl. work | **78,400** |
| | |
| For Asbestos (6 sites @ $25,000 per site) | **150,000** |
| | |
| For sites requiring STJ and air cable boxes (1 site, $10K per site) | **20,000** |
| | |
| Additional panels incl. labour, traffic control (for recloser upgrades) | |
| additional costs associated with HVCs | **50,000** |
| | |
| Total Contingency (nearest $10,000) | **600,000** |

| | |
|---|---|
| Number of sites = | 19 |
| Number of feeders = | 159 |