
# ATTACHMENT 5.06

## Business cases for SCADA and Network Control Protection

Prepared by Endeavour Energy

January 2015

# Zone and Transmission Substations

## *<u>RTU</u>* Renewal Plan

## Program AU004

## Statement of Asset Need

## 1 YEAR PERIOD

## 2014-15

**11 June 2014**

**Prepared**

**Stuart Watts**

Secondary Systems Development Manager

Reviewed:

**Geoff Woods**

SCADA Manager

Endorsed:

**Stephen Lette**

Manager, Secondary Systems

## 1.0 INTRODUCTION

The purpose of this statement of asset need is to obtain approval for the replacement of the SCADA RTUs at seven substations in 2014-15 in order to maintain the required reliability and availability targets for SCADA control and system operations.

This project for RTU replacement is important due to the high rate of failure of RTU modules and the low number of critical spares available.

## 2.0 PROJECT NEED

### 2.1 Failure Rate of RTU Equipment

| | Year RTU Installed | | | Grand Total Faults |
|---|---|---|---|---|
| | 1990- 2004 | 2005- 2009 | 2010-2015 | |
| Hardware Defects recorded between 2008 -2013 | 74 | 39 | 6 | 119 |
| Number of RTU's installed | 103 | 57 | 59 | 219 |
| Failure rate | 0.72 | 0.68 | 0.1 | 0.54 |

The above table shows the number of hardware failures that occurred over the 5 year period July 2008 – June 2013 was 119.

The table also indicates number of failures during this period for each time period that the RTUs were installed. The number of failures (74) for RTUs older than 10 years installed in the 1990-2004 period is significantly high.

Some failures can be repaired, but others such as capacitor failures can permanently damage the printed circuit board. These modules must then be scrapped.

### 2.2 Spare parts usage over the last few years

In 2007, it was foreshadowed that the supply of MD1000 spare parts would dry up as the component manufacturers no longer made the necessary components. Endeavour Energy purchased a one-off last supply of $1m of these MD1000 parts.

The parts purchased for future spares were initially used for augmentation projects rather than replacing the whole substation RTU for minor additional extensions to the SCADA in substations but the high number of these minor extensions added up to deplete the spares required for ongoing maintenance. All critical spares are now managed and restricted for ongoing maintenance only.

The chart below shows only the estimated critical spare parts holdings and usage patterns over the last five years. The number of spares held includes stock in P&C vehicles, regional P&C field service centres and the central store.


At the current rate of failure the present stock would be depleted by 2015, resulting in no spares being available to expand any MD1000 RTU or repair any failed RTUs beyond that date.

A stock take of all RTU parts available from the three Regional P&C depots, P&C vehicles and Glendenning stores was undertaken in August 2013. The summary spares that are deemed critical are listed below (data collected August 2013).

Critical Spares for CGI MDI 1000 type RTU

| Part Number – Type | North | Central | Southern | Stores (Aug 2013) | Total |
|---|---|---|---|---|---|
| PM 121 - processor board | 1 | 31 | 0 | 44 | 76 |
| DCM 110 - power supply board | 4 | 7 | 12 | 0 | 23 |
| MEM-102 – memory board | 0 | 5 | 3 | 32 | 40 |
| ECM 101 – ethernet board | 1 | 2 | 11 | 11 | 25 |

Critical components shown in orange shading such as PM-121, DCM 110 and MEM-102 experience the highest failure rates of all RTU modules and they are also in very low quantities, only sufficient for ongoing maintenance.

ECM boards do not have a high failure rate but are required for interfacing to fibre in the substation and to OPGW / ADSS external fibre connections.

## 3.0 ASSET PROFILE

An analysis and review of the installed RTUs and their profile during the years 1990-2014 is summarised below. The table shows age profile of all zone and transmission substation RTUs currently in service. The oldest RTU was installed in 1990, this single MD 3000 is at Parramatta zone and has been not programmed for renewal as the substation will be decommissioned in 2014.

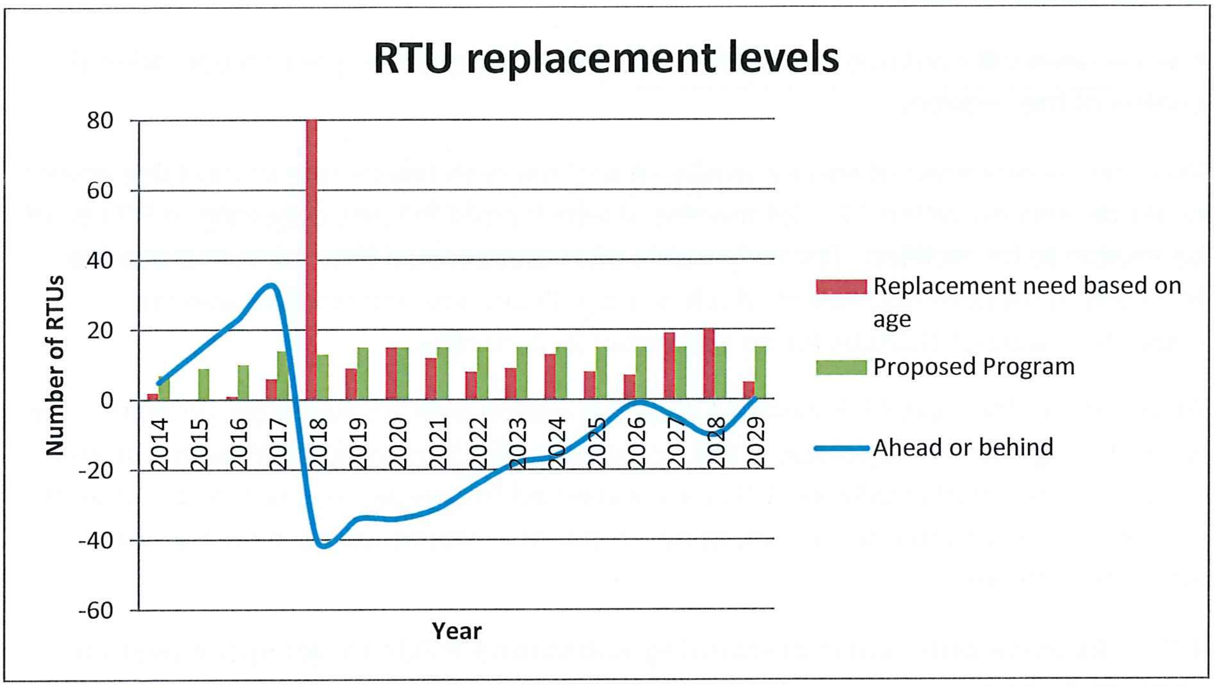
| Year Hardware Installed | ABB RTU 560 | MD300 | MD3311 | MD1000 | MD3000 | Total |
|---|---|---|---|---|---|---|
| 1990 | | | | | 1 | 1 |
| 1999 | | | | 2 | | 2 |
| 2001 | | | | 1 | | 1 |
| 2002 | | | | 6 | | 6 |
| 2003 | | | 3 | 81 | | 84 |
| 2004 | | | 1 | 8 | | 9 |
| 2005 | | | 2 | 13 | | 15 |
| 2006 | | 1 | 1 | 10 | | 12 |
| 2007 | | | | 8 | | 8 |
| 2008 | | | 3 | 6 | | 9 |
| 2009 | 1 | | 2 | 10 | | 13 |
| 2010 | 2 | 1 | 1 | 4 | | 8 |
| 2011 | 5 | | | 2 | | 7 |
| 2012 | 14 | 1 | 1 | 3 | | 19 |
| 2013 | 17 | 2 | | 1 | | 20 |
| 2014 | 5 | | | | | 5 |
| Grand Total | 44 | 5 | 14 | 155 | 1 | 219 |

**Note:** Age relates to most recent significant refurbishment – many of the MD1000 RTUs would have older components than those listed above (particularly those listed as 2003).

RTUs are provided by two suppliers, CGI and ABB, the CGI supplied RTU equipment includes four generations of RTUs, these are MD3000, MD1000, MD3311 and the more recent MD300.

The MD1000 RTU was commissioned from 1999. During 2002- 2003 ninety (90) RTUs were converted from the MD3000 series to MD1000 as a result of the need to control the then newly installed capacitor banks in zone substations. However, the IO modules were not changed therefore several components of these RTUs still date from prior to 1999. Additionally some installations have multiple terminations between the asset being monitored and the RTU IO card, reducing the overall reliability.

The life span for SCADA equipment is generally considered to be 15 years with the limiting factor typically components such as capacitors or batteries. As such with 219 RTUs if there was an even age profile of SCADA equipment approximately 15 RTUs would be required to be replaced each year due to age. Substations that are upgraded for other reasons would normally require the SCADA RTU to be replaced or significantly refurbished at this time and would reduce this requirement.




## 4.0 ASSET RISK

Input from P& C and history records indicate that high levels of failures are being experienced at:

- Bringelly
- Broughton's Pass
- Cabramatta
- Glenmore Park
- Kellyville
- Kangaroo Valley
- Kenthurst

Delaying investment in RTU replacements will only serve to create future problems where a large and potentially unmanageable number of RTUs need to be replaced within a short timeframe. This would potentially put the network reliability and efficiency at risk due to zone and transmission substations not having operational SCADA systems.

## 5.0 RENEWAL OPTIONS

### 5.1 No Replacement

Failure rates will continue to increase with the consequent impact on operational control of the network.

With the current level of spares available and the high failure rate of modules spares could be expired within 12 – 24 months at which point failures occurring in RTUs will be unable to be rectified. The only viable alternative would then be to replace the RTU with a modern equivalent which is a significant job and would leave the substation without SCADA for an estimated 2- 3 months.

At the end of the next AER period 103 RTUs will be over 15 years old (in 2019). This will put a significant proportion of the companies RTUs beyond their technical and economic life. Additionally as RTUs are expected to operate in a hot, dusty, non-air-conditioned environment, the risk of non-repairable failure will be high and will increase with age.

### 4.2 Replace only worst performing substation RTUs to get spare parts for another 5 years

An approach has been made to Jon Neville, SCADA Manager of Essential Energy seeking acquisition of old MD1000 modules as they refurbish their MD1000 RTU fleet, because of their high failure rate. These RTU parts will require modification by CGI to convert them from 48V to 110V DC. It is suspected that this strategy would only be a short term measure as the age of their RTUs is similar to Endeavour Energy and failure rates would continue to remain high.

The RTU replacement at the substations will provide critical spares for maintaining other RTUs. However, critical components which are either unavailable or increasingly difficult to source or repair such as power supplies, CPUs, memory modules, HMI interface and DIU racks will need to be carefully managed and if high failure rates continue to occur the program to refurbish the older RTUs will need to be brought forward.

Maintenance records indicate that the renewal need is urgent for Bringelly, Broughton's Pass, Cabramatta, Glenmore Park, Kellyville, Kangaroo Valley and Kenthurst.

### 4.3 Planned replacement to avoid high failure rates in the next 5-10 years.

This program of works would see 53 RTUs refurbished before the end of the AER (2014-2019). This is expected to provide enough spares to maintain the remaining MD1000 RTUs (102) that will gradually refurbished in the following AER periods.

The aim is to replace the RTUs at 15 years periodically in line with their economic and technical life.

With a refurbishment program to replace 7-14 RTUs every year, the number of RTUs over 15 years old can be reduced to 50 units as shown in the following table. It will take a number of successive AER periods to reduce the age profile to less than 15 years service.

## 6.0 BUDGET

Budget has been allowed in the proposed AER for the next 5 years as shown in the table below

| Code | SAMP No | Description | 2014/15 | 2015/16 | 2016/17 | 2017/18 | 2018/19 |
|---|---|---|---|---|---|---|---|
| AU | AU004 | PM102 ZS SCADA Upgrades | $1.150 | $1.500 | $1.500 | $2.100 | $2.100 |
| Quantity | | | 7 | 9 | 10 | 14 | 13 |

It is estimated that the substation RTU replacement cost varies between $150,000 to $200,000 for the chosen sites. This includes the materials and the labour costs for design, software configuration, testing and commissioning. A contingency of $15,000 per substation has been allowed for unforeseen problems and variations due to site specific conditions.

## 7.0 PROPOSED WORKS

It is proposed to replace seven RTUs over the next year as set out in Attachment A. The scope includes:

- Design, database development and testing
- Replacing substation HMIs (Operator displays)
- Procurement, configuring and programming the new RTUs to communicate in DNP3
- Installation and wiring of the RTUs, re-terminating field devices to the IO modules
- Configuring SCADA Master station and end to end commissioning

## 8.0 RECOMMENDATIONS

That a business case be developed for the replacement of RTUs at the following zone substations:

- Bringelly
- Broughton's Pass
- Cabramatta
- Glenmore Park
- Kellyville
- Kangaroo Valley
- Kenthurst

## Appendix A SAMP Program AER Period 2014-2019

| 2014-2015 | MD3000 Install | MD1000 Refurb | cost | 2015-16 | age | cost | 2016-2017 | age | cost |
|---|---|---|---|---|---|---|---|---|---|
| | | | 7 | | 9 | | | 10 | |
| Broughton Pass (1994 Some Parts) | 1994 | 2005 | $ 81,818 | Kurrajong | 2003 | $ 172,727 | Yennora | 2003 | $ 145,455 |
| Glenmore Park | 1994 | 2003 | $ 181,818 | Bow Bowing | 2003 | $ 181,818 | Douglas Park | 2002 | $ 40,909 |
| Kangaroo Valley | Unknown | 2004 | $ 136,364 | Croom | 2001 | $ 36,364 | Werrington | 2003 | $ 190,909 |
| Kenthurst | 1993 | 2003 | $ 172,727 | Parklea | 2003 | $ 172,727 | Quakers Hill | 2003 | $ 181,818 |
| Kellyville | 1993 | 2002 | $ 154,545 | Minto | 2003 | $ 172,727 | Lennox | 2003 | $ 159,091 |
| Bringelly | 1994 | 2002 | $ 163,636 | Wisemans | 2003 | $ 136,364 | Springwood | 2003 | $ 172,727 |
| Cabramatta | Unknown | 2003 | $ 154,545 | Bowral | 2002 | $ 172,727 | Blaxland | 2003 | $ 145,455 |
| | | | | West Wollongong | 2003 | $ 154,545 | Dundas | 2003 | $ 136,364 |
| | | | | Moss vale | 2002 | $ 163,636 | Narellan | 2003 | $ 181,818 |
| | | | | | | | Prestons | 2003 | $ 172,727 |
| Cost does not include contingency | | | | | | | | | |
| Spend | | | $ 1,045,455 | | | $ 1,363,636 | | | $ 1,527,273 |

| 2017-18 | | age | cost | 2018-19 | age | cost |
|---|---|---|---|---|---|---|
| | | 14 | | | 13 | |
| Arndell Park | | 2003 | $ 163,636 | Unanderra | 2003 | $ 159,091 |
| Blacktown | | 2003 | $ 200,000 | Warilla | 2002 | $ 136,364 |
| Dendrobium | | 2003 | $ 40,909 | Albion Park | 2003 | $ 154,545 |
| Bonnyrigg | | 2003 | $ 159,091 | Fairfax Lane | 2002 | $ 163,636 |
| West Castle Hill | | 2003 | $ 168,182 | Whalan | 2003 | $ 168,182 |
| Inner harbour | | 2003 | $ 145,455 | Emu Plains | 2003 | $ 163,636 |
| North Rocks | | 2003 | $ 145,455 | Kenny Street | 2003 | $ 150,000 |
| Jamberoo | | 2003 | $ 45,455 | Liverpoool 11kV | 2003 | $ 163,636 |
| Kembla Grange | | 2003 | $ 136,364 | North Richmond | 2003 | $ 163,636 |
| Ilford | | 2003 | $ 95,455 | Riverstone | 2003 | $ 150,000 |
| Ambarvale | | 2003 | $ 163,636 | Shellharbour | 2003 | $ 163,636 |
| Woodpark | | 2003 | $ 145,455 | Jerrara | 2003 | $ 36,364 |
| Katoomba North TS | | 2003 | $ 145,455 | South Wollongong | 2003 | $ 136,364 |
| Kingswood | | 2003 | $ 154,545 | | | |
| | | | | | | |
| | | | | | | |
| Spend | | | $ 1,909,091 | | | $ 1,909,091 |

Cost does not include contingency

## APPENDIX B Substation RTU Issues

### 1. **Broughtons Pass** Installed 2005

| No | Defect | Date | Rectification/Replacement |
|---|---|---|---|
| 1 | HMI obsolete | 2012 | Not available |
| 2 | DIU26 AIM card faulty | Apr 2011 | AIM card |

### 2. **Glenmore Park** Installed 2003

| No | Defect | Date | Rectification/Replacement |
|---|---|---|---|
| 1 | 11kv ARC inoperable from MS | 17 Oct 2013 | Memory error-Reset |
| 2 | DIU18 fail | 18 Sep 2013 | PM Module |
| 3 | Control room Informed that while switching CB they lost DIU 17,18 and 27 | 21 Sep 2013 | 3 * PM Modules replaced |
| 4 | Multiple module failures | Aug 2013 | PM module |
| 5 | Operator complained that he had lost indication of some of the 11kV CB's | 21 July 2013 | Found DIU 27 crashed. Unable to talk to other DIU's. Replaced PM, downloaded site strings and db, all ok |
| 6 | DIU17, 18, 27 not communicating | Sep 2011 | RS485 drivers damaged |
| 7 | DIU2, 15 chassis replaced | Apr 2011 | Cables crushed, re-terminated |
| 8 | Module failures | Apr 2010 | PM module |
| 9 | DIU 17, DIU 27 failures | Nov 2010 | PM module |
| 10 | HMI not working | Jul 2010 | HMI (Monitor) replaced |

### 3. **Kangaroo Valley** Installed 2003

| No | Defect | Date | Rectification/Replacement |
|---|---|---|---|
| 1 | O/C indication not working on KVA2 | 23 Aug 2007 | Rectified |
| 2 | Fault current reported incorrect | 23 Aug 2007 | Rectified |
| 3 | MD3-DNP3 conversion to address issues 1 and 2 | 2008 | DIM cards and RS485 converters replaced |
| 4 | 33kV Recloser runs of separate recloser RTU | NA | NA |

### 4. **Kenthurst** Installed 2003

| No | Defect | Date | Rectification/Replacement |
|---|---|---|---|
| 1 | Station level SEF not operating | 14 Sep 2013 | DOM-101 |
| 2 | CB S743 unable to close | Jan 2012 | PM, POM, DCM-110 |

| | | | |
|---|---|---|---|
| 3 | DIM | Jan 2011 | CB Failed to reclose |
| 4 | DIU27 | Jul 2011 | PM module, RS485 driver |
| 5 | CB fault | Oct 2010 | PM module |

5. **Kellyville** Installed 2003

| No | Defect | Date | Rectification/Replacement |
|---|---|---|---|
| 1 | All 33kV CBs indeterminate | 9 Sep 2013 | Module 15 Power supply failure |
| 2 | SOP unable to open CBs | 3 May 2012 | LCR aborts |
| 3 | RTU Comms failure | 12 Apr 2012 | Rack 1, Rack 2(PM121) |
| 4 | Relay comms-Radio comms failure | 23 Apr 2012 | SMM card replaced |
| 5 | CPU failure | 29 Mar 2012 | Restart RTU |
| 6 | HMI (screen) failure | 7 Jul 2011 | Replaced with touch screen |
| 7 | Defective RTU screen | 28 Oct 2010 | |

6. **Cabramatta** Installed 2003

| No | Defect | Date | Rectification/Replacement |
|---|---|---|---|
| 1 | CBs not operating from remote | 9 Nov 2012 | POM-103 |
| 2 | Tx Tap reached top tap (VR routine?) | 26 Nov 2011 | Heat/dust on RTU cards |
| 3 | POM-103 faulty | 22 Mar 2011 | Replaced DIU2-POM-103 |
| 4 | HMI(Dell PC ) faulty | 18 Feb 2010 | Replaced PC |

7. **Bringelly** Installed 2003

| No | Defect | Date | Rectification/Replacement |
|---|---|---|---|
| 1 | Medical Emergency test failed | 5 Dec 2012 | POM-103 |
| 2 | Analogues failed | 18 Oct 2010 | Two AIM cards replaced |

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# Memorandum

| | | | |
|---|---|---|---|
| To | Chief Operating Officer | File no | AU004 |
| From | Manager Asset and Network Planning | Date | 15 August 2014 |
| Subject | Transmission and Zone Substation SCADA RTU replacements | | |
| Copies | | | |

## Purpose

The purpose of this memo is to seek approval to fund the next stage of the program of replacement of transmission and zone substation SCADA RTU equipment which is experiencing high rates of failure indicating that it has reached the end of its life.

## Background

The SCADA remote terminal units (RTUs) in transmission and zone substations enable the substation circuit breakers to be operated remotely from the master station(s) at Huntingwood and Coniston and also from the Human-machine interface (HMI) panel in the substation itself.

The RTUs also facilitate capture of circuit breaker status and substation and feeder voltage and current levels, transformer temperatures and other analogue and digital data and implement a range of control functions in the substation.

The control functions carried out by SCADA in a typical zone substation include:

- Voltage Regulation;
- Transformer and feeder auto-changeover;
- Feeder auto-reclose;
- Load control (including streetlights and hotwater systems);
- Capacitor control;
- SEF protection enabling;
- Substation medical emergency button.

Subsequently, a failure of the SCADA system in a zone substation can affect a significant range of functions resulting in an impact on reliability, safety and customer satisfaction.

Furthermore, failure of the SCADA system in a substation requires manual intervention which reduces the safety for operational staff requiring them to operate circuit breakers from in front of the breaker panel (instead of remotely) and introduces significant delays in configuring the network during emergency situations. Failures also remove the visibility of all or parts of the substation to the system operators reducing their ability to effectively operate the network.

Therefore, ensuring the reliable operation of the substation SCADA systems including the RTUs is a high priority and the equipment is scheduled for replacement when failure rates of individual units within the substation start to increase above reasonable levels.

The SCADA RTUs at Bringelly, Broughton Pass, Cabramatta, Glenmore Park, Kellyville, Kangaroo Valley and Kenthurst zone substations are aged MD1000 units installed in the early 2000's which are experiencing high rates of failure and are proposed to be replaced in the 2014/15 year to ensure the ongoing visibility and operational capability of those substations.

The replacement costs are a function of the size and complexity of the substation and vary from $85,000 to $182,000 for the seven substations above giving a total proposed expenditure for this part of the program of $1.05 million. A contingency amount of $100,000 is proposed for unforseen issues which may be experienced due to the work taking place within existing aged substations, giving an estimated total project cost of $1.15 million.

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The current SARP 2014/15 includes a funding allocation under program AU004 of $1.15 million in 2014/15 which is adequate for the proposed works.

The program summary in the PIP (rev 3.3a) gives program AU004 a risk level of "High", a weighted ranking of 9,000 and a percentage of 75.25%. Arguably this indicates a lower priority for this project than the impacts resulting from SCADA RTU failure suggest. However, it is anticipated that issues such as this will be corrected as a result of the current Group-led review of the CASH ranking methodology.

Refer attached business case for further detail of the program.

## Recommendation

It is recommended that the Chief Operating Officer approve:

1. Expenditure of $1.05 million during 2014/15 to replace RTUs at the seven substations listed above;
2. A contingency amount of $100,000 representing 10% of the estimated cost of the project to cover unforseen issues which may arise during installation works.

The complete project estimate, including the contingency sum, for which approval is sought, totals $1.15 million.

**Prepared:**

Rick Wallace
**Manager Asset and Network Planning**

**Endorsed:**

19/8/14

Jim Battersby
**Chief Engineer**

**Approved:**

2/9/14

Rod Howard
**Chief Operating Officer**

# TRANSMISSION AND ZONE SUBSTATIONS SCADA RTU REPLACEMENTS

## Project AU004

Prepared by Asset and Network Planning

JULY 2014

Endeavour Energy

## REVIEW AND APPROVAL SCHEDULE

| Responsibility | Position | Name | Signature | Date |
|---|---|---|---|---|
| Authored | Renewal Project Development Officer | Vasan Naidoo | | |
| Reviewed | Senior Renewal Project Development Engineer | Jonathan Cook | | |
| Endorsed | Network Investment Planning Manager | Manoraj Jayasekara | | |
| Endorsed | Manager Asset and Network Planning | Rick Wallace | | |
| Approved | Chief Engineer | Jim Battersby | | |

## DOCUMENT AND AMENDMENT SCHEDULE

| Version | Approval date | Comments | Updates |
|---|---|---|---|
| 1.0 | June 2014 | Initial release | |
| | | | |
| | | | |
| | | | |
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# 1.0 EXECUTIVE SUMMARY

Central control of Endeavour Energy's electrical network is made possible by the Supervisory Control and Data Acquisition (SCADA) system which incorporates Remote Terminal Units (RTUs) at transmission and zone substations linked to the master station in the control rooms at Huntingwood and Coniston.

System operators operate remote field devices by sending control signals from the SCADA master station to the field RTUs which interface with field devices such as circuit breakers. Network parameter data such as current and voltage and equipment status information from substations is relayed from the substations to the SCADA master station via the substation RTUs.

An RTU generally has a life expectancy of around 15 years due to the ageing of capacitors and other components that are mounted on their printed circuit boards. As RTUs age their failure rates increase and failure data over a five year period, from 2008 to 2013, indicates a 72% failure rate associated with RTUs that are more than 10 years old.

This business case seeks approval for the funding to replace RTUs which are experiencing high failure rates in seven zone substations as proposed by the Statement of Asset Need issued by Manager Secondary Systems.

The majority of RTUs that are failing are of the MD1000 type that was installed in the early 2000s. This product was discontinued in 2007 and stock levels of MD1000 spare components are now at low levels.

This proposal seeks to replace the RTUs during 2014/15 at the following seven zone substations that have been identified as having high rates of failures:

- Bringelly;
- Broughton's Pass;
- Cabramatta;
- Glenmore Park;
- Kellyville;
- Kangaroo Valley; and
- Kenthurst.

The RTUs at each of these substations will be replaced with the current CGI RTU MD300 model.

The cost of replacing the RTUs at these substations varies from $85,000 to $182,000 giving an estimated cost for works at these locations of $1.05 million. Furthermore, a contingency sum of $100,000 representing 10% of the cost the project is proposed to cover unforseen issues which may arise during installation works including the provision of temporary SCADA RTUs during the replacement process.

It is expected that the work will be completed in 2014/15.

Funding for these works has been provided in SARP program AU004 and the PIP.

Accordingly, it is recommended that:

- A capital expenditure of $1.05 million to replace RTUs at the seven locations listed in this document during 2014/15 be approved;
- A contingency sum of $100,000, representing 10% of the estimated cost of the project to cover unforseen issues which may arise during installation works, be approved.

The complete project estimate, including the contingency sum for which approval is sought, totals $1.15 million.

# 2.0 INTRODUCTION

Remote terminal units (RTUs) are used at substations and within field devices to enable the remote control of elements of the electrical network and to acquire system parameter data for network control purposes. Substation RTUs communicate with the Supervisory Control and Data Acquisition (SCADA) system via radio or optical fibre thereby facilitating network control and data recording.

This project is a component of Endeavour Energy's five year SARP program (AU004) which is aimed at replacing RTUs and SCADA related equipment that are in poor condition in zone and transmission substations.

An RTU replacement policy will be developed across the three Network NSW business units in the 2014/15 financial year which will examine strategies for RTU replacements in future years. Therefore this business case is an interim measure and is limited to the 2014/15 financial year to satisfy the urgent needs at particular sites.

# 3.0 PROJECT NEED

## 3.1 STATEMENT OF ASSET NEED

Manager, Secondary Systems has issued a statement of asset need (SAN), which recommends the replacement of MD1000 SCADA RTUs at seven substations in the 2014/15 year. The SAN highlights reliability issues and advises of a substantial decline in the stock levels of components used for MD1000 RTU repairs. Refer Appendix A for details of the SAN.

## 3.2 ASSET DETAILS

RTUs used at Endeavour Energy are provided by two suppliers, CGI (Logica) and ABB. CGI RTU models are:

- MD3000;
- MD1000;
- MD3311; and
- MD300.

ABB supply the more recent RTU 560 models. Endeavour Energy currently use both ABB 560 and CGI's MD300 models. The ABB models are mainly used at "greenfield" sites and the CGI models are used at existing sites that were fitted with MD1000 units as it is easier and more cost effective to upgrade the existing program in the MD1000 to work with the MD300 model than to re-write new programs for the ABB model.

During 2002/3, 90 MD3000 series RTUs were converted to MD1000's to control the capacitor banks in zone substations. Only one MD3000 RTU is left in service at the soon to be decommissioned Parramatta ZS. The input and output modules of the MD3000 units were not replaced in the 2002/3 conversion program therefore these components of the upgraded MD3000 to MD1000 units are of the original pre-1999 vintage.

Table 1 below shows the spread of RTU models in service and the dates when the last upgrades were carried out.



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TABLE 1: RTUS CURRENTLY IN SERVICE

| Year hardware installed | ABB RTU 560 | MD300 | MD3311 | MD1000 | MD3000 upgraded to MD1000 | MD3000 | Total |
|---|---|---|---|---|---|---|---|
| 1990 | | | | | | 1** | 1 |
| 1999 | | | | | | | 0 |
| 2001 | | | | | | | 0 |
| 2002 | | | | | | | 0 |
| 2003 | | | 3 | | 90* | | 93 |
| 2004 | | | 1 | 8 | | | 9 |
| 2005 | | | 2 | 13 | | | 15 |
| 2006 | | 1 | 1 | 10 | | | 12 |
| 2007 | | | | 8 | | | 8 |
| 2008 | | | 3 | 6 | | | 9 |
| 2009 | 1 | | 2 | 10 | | | 13 |
| 2010 | 2 | 1 | 1 | 4 | | | 8 |
| 2011 | 5 | | | 2 | | | 7 |
| 2012 | 14 | 1 | 1 | 3 | | | 19 |
| 2013 | 17 | 2 | | 1 | | | 20 |
| 2014 | 5 | | | | | | 5 |
| Total | 44 | 5 | 14 | 65 | 90 | 1 | 219 |

* These RTUs have older input output modules.

** Unit at Parramatta ZS to be decommissioned in 2014/15

### 3.3 ASSET CONDITION AND RENEWAL NEEDS

Components and circuit boards within the RTUs have a high failure rate, which increases with age as indicated in Table 2 below.

TABLE 2: FAILURE RATES OF RTUS IN THE PAST 5 YEARS - FROM 2008 TO 2013

| Age category in years | Number of failures | Population size | Failure rate |
|---|---|---|---|
| >10 | 74 | 103 | 72% |
| 5-9 | 39 | 57 | 68% |
| 0-5 | 6 | 59 | 10% |
| Totals | 119 | 219 | 54% |

Recorded hardware failures shown in Table 2 are a combination of component failures as well as complete printed circuit board failures. Some component failures are minor allowing the board to be repaired by replacing the individual components whilst failures of capacitors that are mounted on the circuit boards may result in irreparable damage to the printed circuit boards requiring complete replacement of the board.

RTUs generally last for around 15 years before failure rates become excessive. The age profile of the current population requires that approximately 15 units be replaced each year to maintain the age profile and reliability.

### 3.4 PRODUCT OBSOLESCENCE AND SPARE PARTS STRATEGY

In 2007, CGI discontinued the MD1000 series RTUs and support for this type is not available. Subsequently, Endeavour Energy purchased a large quantity of spare parts to support the maintenance and repair of the existing population of MD1000 RTUs in the system for an estimated further 10 years (until 2017).

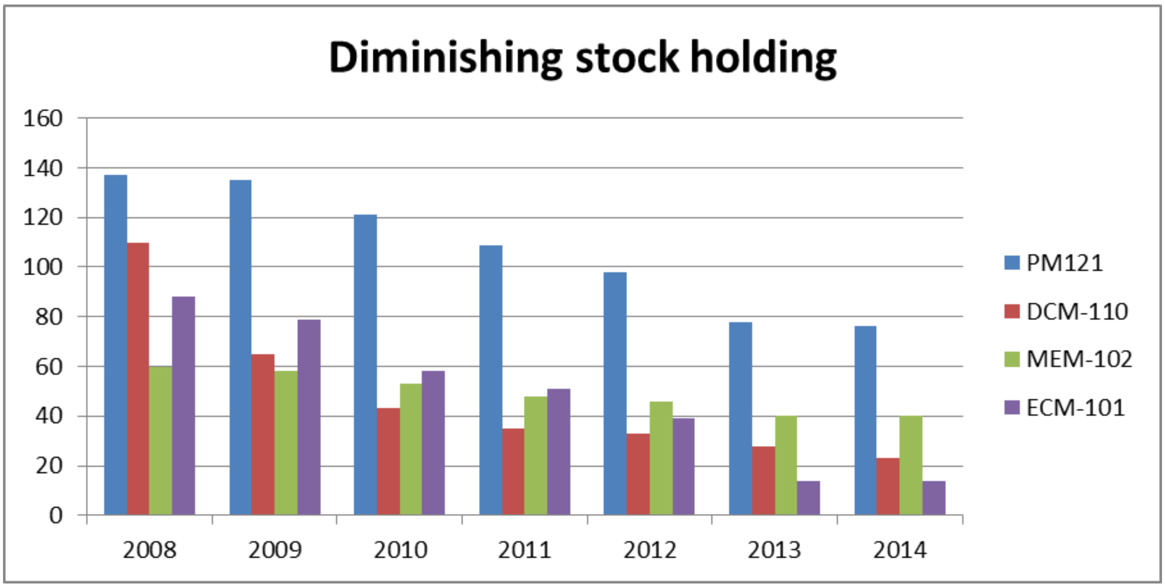
However, large quantities of these spare parts, were consumed to enable the various substation augmentation programs resulting in a significant drop in inventory levels and reducing our ability to maintain these RTUs.

Refer Figure 1 below which highlights the diminishing inventory of spare parts related to the MD1000 RTUs:

- PM121 - Processor module – 76 units;
- DCM-110 - DC-DC Converter - 23 units;
- MEM-102 - Memory module – 40 units remaining; and

- ECM-101- Ethernet board – 25 units remaining.

Figure 1: INVENTORY OF THE MD1000 RTU SPARE PARTS




Current failure rates of MD1000 RTUs suggest that the existing stock levels will be consumed by 2015. However, components of RTUs that are replaced under the AU004 renewal program will be retained to boost the inventory to enable the remaining MD1000 units to be retained in service beyond 2015.

Currently Endeavour Energy has 90 MD1000 RTU hybrid units and a further 65 newer MD1000's giving a total of 155 MD1000's RTUs in the system.

Although the strategy for RTU replacement beyond 2014/15 is currently being considered by Network NSW, SARP program AU004 proposes the replacement of 53 RTUs over the next five year period from 2014/15 to 2018/19. Table 3 below is an extract from the SARP and shows the proposed quantities and expenditure over the next five years.

TABLE 3: SARP PROGRAM AU004 FOR NEXT FIVE YEARS

| | 2014/15 | 2015/16 | 2016/17 | 2017/18 | 2018/19 |
|---|---|---|---|---|---|
| Budgeted amount in $ millions | $1.150 | $1.500 | $1.500 | $2.100 | $2.100 |
| Quantity per year | 7 | 9 | 10 | 14 | 13 |

### 3.5 TARGETED SITES FOR 2014/15

Historical records indicate high levels of failures of MD1000 RTUs at the following zone substations:

- Bringelly;
- Broughton's Pass;
- Cabramatta;
- Glenmore Park;
- Kellyville;
- Kangaroo Valley; and
- Kenthurst.

Refer Table 4 below for a failure history of the RTU equipment at these sites.

TABLE 4: FAILURE HISTORY OF RTUS AT TARGETED SITES

| Zone Substation | Defect | Date | Comment |
|---|---|---|---|
| Bringelly | Medical Emergency test failed | 5/12/2012 | POM-103 replaced |
| | Analogs failed | 18/10/2010 | Two AIM cards replaced |
| Broughton's Pass | HMI obsolete | 01/01/2012 | Not available |
| | DIU26 AIM card faulty | 01/04/2011 | AIM card |
| Cabramatta | CBs not operating from remote | 09/11/2012 | POM-103 replaced |
| | Tx Tap reached top tap (VR routine?) | 26/11/2011 | Heat/dust on RTU cards |
| | POM-103 faulty | 22/03/2011 | Replaced DIU2-POM-103 |

| Zone Substation | Defect | Date | Comment |
|---|---|---|---|
| | HMI(Dell PC ) faulty | 18/02/2010 | Replaced PC |
| Glenmore Park | 11kv ARC inoperable from MS | 17/10/2013 | Memory error-Reset |
| | DIU18 fail | 18/09/2013 | PM Module |
| | Control room Informed that while switching CB they lost DIU 17,18 and 27 | 21/09/2013 | 3 * PM Modules replaced |
| | Multiple module failures | 01/08/2013 | PM module |
| | Operator complained that he had lost indication of some of the 11kV CB's | 21/07/2013 | Found DIU 27 crashed. Unable to talk to other DIU's. Replaced PM. |
| | DIU17, 18, 27 not communicating | 01/09/2011 | RS485 drivers damaged |
| | DIU2, 15 chassis replaced | 01/04/2011 | Cables crushed, re-terminated |
| | Module failures | 01/04/2010 | PM module |
| | DIU 17, DIU 27 failures | 01/11/2010 | PM module |
| | HMI not working | 01/07/2010 | HMI (Monitor) replaced |
| Kellyville | All 33kV CBs indeterminate | 09/09/2013 | Module 15 Power supply failure |
| | SOP unable to open CBs | 03/05/2012 | LCR aborts |
| | RTU Comms failure | 12/04/2012 | Rack 1, Rack 2(PM121) |
| | Relay comms-Radio comms failure | 23/04/2012 | SMM card replaced |
| | CPU failure | 29/03/2012 | Restart RTU |
| | HMI (screen) failure | 07/07/2011 | Replaced with touch screen |
| | Defective RTU screen | 28/10/2010 | Rectified |
| Kangaroo Valley | O/C indication not working on KVA2 | 23/08/2007 | Rectified |
| | Fault current reported incorrect | 23/08/2007 | Rectified |
| | MD3-DNP3 conversion to address issues 1 and 2 | 01/01/2008 | DIM cards and RS485 converters replaced |
| Kenthurst | Module failure | 06/12/2013 | Faulty comms module |
| | Station level SEF not operating | 14/09/2013 | DOM-101 |
| | CB S743 unable to close | 01/01/2012 | PM, POM, DCM-110 |
| | DIM | 01/01/2011 | CB Failed to reclose |
| | DIU27 | 01/07/2011 | PM module, RS485 driver |
| | CB fault | 01/10/2010 | PM module |

## 3.6 RISK ASSESSMENT

The risk assessment shown in Table 5 below utilises Endeavour Energy's risk management procedure GRM 0003 [1] to quantify the risks associated with ageing RTU equipment.

TABLE 5 –BUSINESS RISK ASSESSMENT

| Asset | Event | Likelihood | Impact | Risk rating | Consequence and Comments | Proposed Treatment | Expected Risk after Treatment |
|---|---|---|---|---|---|---|---|
| RTU | Failure of an RTU input / output module | Likely (B) | Minor (2) | Medium (B2) | Loss of operation of one circuit breaker. Operator attends site and manually switches breaker. | Repair or replace RTU input / output module (assuming parts are available). | Medium (B2) |
| | Failure of an RTU | Likely (B) | Minor (2) | Medium (B2) | In small zone substations having only one RTU, an RTU failure will result in loss of remote control of this substation. Larger substations have multiple RTUs therefore the loss of one RTU will result in loss of control to sections of the substation. | Replace RTUs at locations that have a high number of failures with new RTUs. | Low (D2) |
| | Failure of multiple RTUs | Likely (B) | Moderate (3) | **High (B3)** | Insufficient parts available<br>Loss of remote control of parts of the network<br>Outages<br>Safety issues | Replace RTUs | Low (D2) |
| | Failure of RTU power supply | Likely (B) | Moderate (3) | **High (B3)** | Loss of visibility and remote control of the substation | Repair power supply unit or replace RTU's depending on available spares, age and failure rates | Low (D2) If RTUs are replaced |

As shown in Table 5, the risk level with the existing RTUs is high. This risk level will be reduced to low if these RTUs are replaced with new RTUs.

### 3.6.1 CONCLUSION

Based on the assessment of the project need and the risk, it is concluded that the aged RTU's at the seven zone substations noted should be replaced in the short term.

# 4.0 PROJECT DETAILS

## 4.1 PROJECT SCOPE

The scope of works includes:

- Replacing the RTUs at the seven zone substations noted with MD300 RTUs;
- Replacing HMI displays if required;
- Design, database development and testing;
- Configuring the SCADA Master station; and
- End to end commissioning of the systems.

# 5.0 PROJECT COSTS AND FUNDING

## 5.1 COST ESTIMATE

The estimated cost of the proposed works is shown in Table 6 below. The cost variation from site to site is based on the complexity of the substation, quantity of hardware components and labour requirements.

TABLE 6: ESTIMATED COSTS OF OPTION 2

| Zone Substation | Cost Estimate |
|---|---|
| Bringelly | $ 165,000 |
| Broughton's Pass | $ 85,000 |
| Cabramatta | $ 155,000 |
| Glenmore Park | $ 182,000 |
| Kellyville | $ 155,000 |
| Kangaroo Valley | $ 136,000 |
| Kenthurst | $ 172,000 |
| Sub Total | $1,050,000.00 |
| 10 % Contingency allowance | $ 100,000 |
| Total funding required | $1,150,000.00 |

## 5.2 CONTINGENCY PROVISION

The following additional works are required in some sites during the SCADA RTU replacement. It is generally not possible to identify the scope of these works required until the works are commenced. Therefore an overall contingency allowance has been made rather than individual funding in the base cost estimate for each site.

The contingency works which may be required at some sites:

- The development of site specific RTU schematics (as none exist for these sites) by on site verification and tracing of circuitry;
- The RTUs and SCADA system has to be kept alive whilst the new RTUs are installed. Therefore the installation process has to provide temporary RTU's functionality whilst the existing RTUs are replaced in situ;
- To allow for rationalisation of panel wiring that may be required to standardise the existing legacy systems;
- In previous RTU replacements multiple termination points, which impact on reliability were found. Therefore the contingency provision will allow for the rationalisation of these terminations if required;
- To resolve protocol issues between existing protection relays and the new MD300 RTUs if required.

## 5.3 PORTFOLIO INVESTMENT PLAN

The program summary for AU004 in the Project Investment Portfolio (PIP) is shown in Table 7 below and reflects the risk level and priority of this project.



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TABLE 7: PIP SUMMARY

| PIP element | PIP rating |
|---|---|
| Project ID | AU004a |
| Principal driver | Renewal |
| Risk level | High |
| Weighted ranking | 9,000 |
| Percentage | 72.22% |

## 5.4 PROGRAM FUNDING

The SARP 2014/15 plan and PIP includes funding allocations under program AU004 of $1.150 million in 2014/15 which is adequate for this project. Table 8 below shows the provision for the proposed works in the PIP.

TABLE 8: ESTIMATED EXPENDITURE SPREAD

| Item | Expenditure ($M) | | | |
|---|---|---|---|---|
| | 2014/15 | 2015/16 | 2016/17 | Total |
| PIP provision ($,000 nominal) | 1,150 | 1,538 | 1,576 | **2,261** |
| Estimated expenditure in real (2014/15) $ - this project | 1,150 | | | |
| Carryover from previous year | | | | |
| Remaining $ | 1,150 | | | |

## 5.5 TIMING

These works are expected to be completed during 2014/15.

# 6.0 RECOMMENDATIONS

Based on above analysis, the proposal to replace the existing MD1000 RTUs in the nominated substations with modern MD300 RTUs is recommended.

Accordingly, it is recommended that:

- A capital expenditure of $1.05 million to replace RTUs at the seven locations listed in this document during 2014/15 be approved;
- A contingency sum of $100,000, representing 10% of the estimated cost of the project to cover unforseen issues which may arise during installation works, be approved.

The complete project estimate, including the contingency sum for which approval is sought, totals $1.15 million.

# 7.0 APPENDICES

**APPENDIX A -** Statement of asset need

# 8.0 REFERENCES


1. Endeavour Energy Company Procedure GRM0003 Risk Management, Risk Manager, 30/08/11

## APPENDIX A

STATEMENT OF ASSET NEED.

Endeavour Energy

# Memorandum

| | | | |
|---|---|---|---|
| To | Network Investment Planning Manager | File no | |
| From | Protection Manager | Date | 24 September 2014 |
| Subject | Protection SARP PS008 – Increase in expenditure | | |
| Copies | Manager Secondary Systems, Manager Asset & Network Planning | | |


**Summary**

Protection scheme renewal expenditure (currently PS008) will need to increase substantially in coming years primarily due to:

- the end of design life and excessive failure rates of protection relays which incorporate electronics, and;
- functional redundancy of both electromechanical and electronic systems making the relay no longer suitable for the task, or if replacement with state of the art systems gives us the ability to enhance the safety, reliability, or cost to serve performance, and;
- compliance of our systems, both electromechanical and electronic, with the National Electricity Rules, particularly with regards to redundancy at the distribution feeder level.


**Electronic relay life expectancy**

The life expectancy of protection relays incorporating electronics is much lower than their electromechanical counterparts, the life expectancy being between 10 and 25 years. The design life for protection systems is listed as 10 years in Company Policy 9.2.5, Network Asset Design.

In some models we have already seen elevated and unsatisfactory failure rates at between 10 and 15 years after commissioning. Some of these failures have resulted in protection maloperations or the failure to operate and properly clear faults.

For example, the GE SR750/760 series microprocessor overcurrent relays are now between 10 and 15 years old. We have experienced 6 failures out of a population of 114 over a period of 5 weeks at the end of last summer. This represents over 5% of the population in a 5 week period. The failures were experienced across multiple sites, and not all failures resulted in relay failure watchdog alarms. One such failure, on the 29 March 2014 resulted in the loss of 2 bus sections at Parklea Zone Substation for nearly an hour, contributing 0.4 minutes of SAIDI.

Similarly, there have been multiple failures of GE SR745 microprocessor transformer differential relays, population of 102, some of these resulting in unwarranted tripping of in service transformers, and one resulted in the failure of the differential to operate for a genuine transformer fault.

These failures are not of consistent failure modes. Examples of the failure modes experienced include microprocessor failure, power supply failure, and output contact failure. The manufacturer has been queried and has responded that *"some components are at the end of their life cycle".*

The replacement of these GE SR series relays alone, most of which are not yet 15 years of age would cost approximately $5 million.

## Functional redundancy

Irrespective of their life expectancy and failure rates, both electromechanical and electronic relays may become redundant through difficulties or due to the risks of maintaining them in service, or to take advantage of the safety, reliability, or cost opportunities that are gained by replacing them with state of the art systems.

For example, modern microprocessor relays might become redundant when the software required to set, test, and download settings and fault records is no longer compatible with current operating systems or hardware, or when the communications protocol is no longer compatible with SCADA systems when they are upgraded. Electromechanical relays might become redundant when the communications medium is upgraded from copper to fibre, making the relay incompatible and replacement necessary.

## Opportunities to enhance safety, bushfire risk mitigation, reliability and cost to serve

As well as redundancy, there are opportunities provided by upgrading the relays or protection systems, if they are no longer state of the art. Some examples include:

- The installation of core balance CT's and the upgrade of sensitive earth fault protection relays that can increase sensitivity from 4A to 1A, increasing the likelihood of detection and decreasing the risk of injury or bushfire.

- Improve safety by providing faster clearing times, and operator controlled instantaneous protection, which remotely allows the activation of instantaneous protection for live line work, switching operations, or during periods of high bushfire danger, reducing the risk of bushfire or degree of burns following a cable cut in or switching accident.

- A reduction in outage times, by providing distance to fault, or fault level information to control room operators

- A reduction in the cost of maintenance activities, for example, circuit breaker maintenance can be reduced by basing maintenance on the actual fault levels and on which phases the fault occurred, rather than assuming the maximum fault level on all three phases.

- Improve power quality for sensitive customers by reducing high fault level clearance times

## Redundancy (reliable protection operation)

A large proportion of our protection systems do not have comprehensive backup for relay or circuit breaker failure. This applies to the majority of distribution feeders with only a single overcurrent protection relay installed. In the case of a relay or circuit breaker failure, faults may have to reach as high as 6kA before being detected by other protection systems. Given that distribution feeder faults are frequent, there is a reasonable likelihood of an uncleared fault on our system. This risk is higher than ever before, because we now have a very high quantity of modern relays, their failure rates being much poorer than electromechanical relays, and because electromechanical relays are in practice provided as a set of 3 independent relays so there is some redundancy for most fault types in the case of relay failure.

Of note is that most of the GE SR750/760 series relays described above are installed as non-redundant single distribution feeder protection systems.

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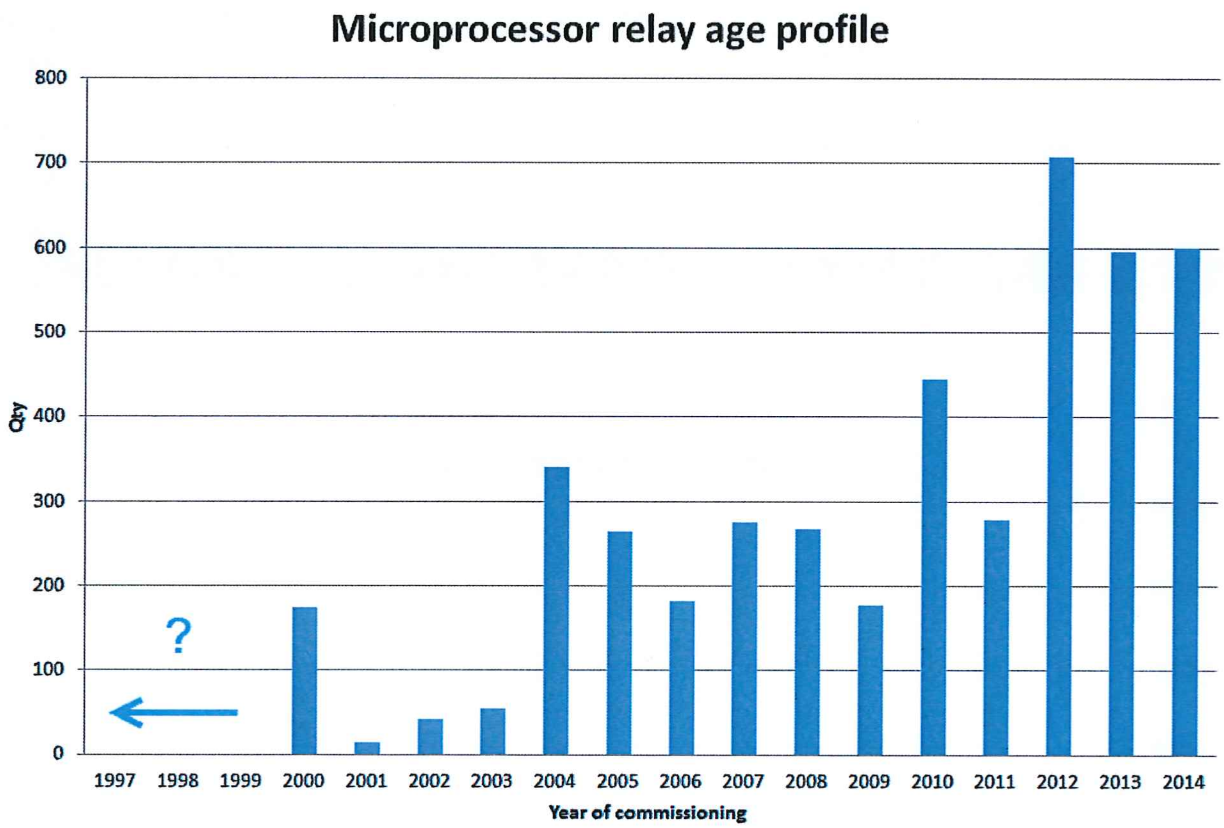
The National Electricity Rules (S5.1.9) states that *"a Network Service Provider must provide sufficient primary protection systems and back-up protection systems (including breaker fail protection systems) to ensure that a fault of any fault type anywhere on its transmission system or distribution system is automatically disconnected..."*

In order to minimise the risk of uncleared faults, and to be compliant with the National Electricity Rules, it is recommended that these non-redundant systems be replaced with new and redundant systems when they are replaced.

**Microprocessor relay age profile**

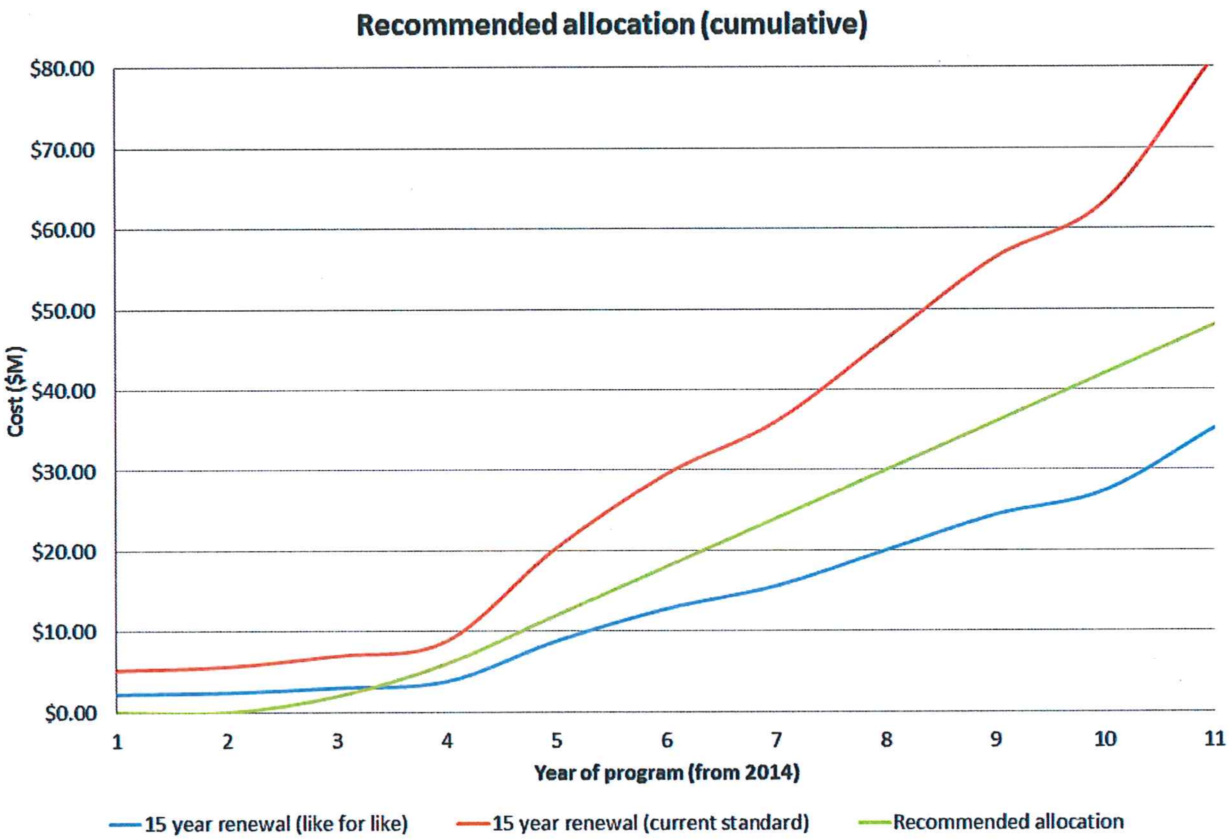
The chart below displays the age profile of microprocessor relays. The data in Ellipse has some integrity issues but this is the best we have to work with at the moment. Attempts will be made to enhance the data integrity over the next 12 months.



**Cost of renewal**

The cost of renewal of modern microprocessor relays based on current Ellipse data and a 15 year life cycle is:

| Year | Modern relay (15 year replacement cycle) | | | | Old electromechanical replacement $M | Total Suggested PS008 $M |
|---|---|---|---|---|---|---|
| | Qty | Replacement cost (like for like) $M | Replacement cost (current standard) $M | Suggested $M | | |
| 2014-15 | 174 | $2.26 | $5.22 | $0.0 | $1.60 | **$1.60** |
| 2015-16 | 14 | $0.19 | $0.43 | $0.0 | $1.93 | **$1.93** |
| 2016-17 | 42 | $0.58 | $1.34 | $2.0 | $2.06 | **$4.06** |
| 2017-18 | 55 | $0.78 | $1.80 | $4.0 | $2.00 | **$6.00** |
| 2018-19 | 341 | $4.99 | $11.51 | $6.0 | $2.00 | **$8.00** |
| 2019-20 | 264 | $3.98 | $9.18 | $6.0 | $2.00 | **$8.00** |
| 2020-21 | 182 | $2.83 | $6.52 | $6.0 | $2.00 | **$8.00** |
| 2021-22 | 276 | $4.41 | $10.18 | $6.0 | $2.00 | **$8.00** |
| 2022-23 | 268 | $4.41 | $10.18 | $6.0 | $2.00 | **$8.00** |
| 2023-24 | 177 | $3.00 | $6.93 | $6.0 | $2.00 | **$8.00** |
| 2024-25 | 445 | $7.77 | $17.94 | $6.0 | $2.00 | **$8.00** |
| **TOTALS** | **2238** | **$35.21** | **$81.25** | **$48.0** | **$21.6** | **$69.6** |



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**Recommendation**

It is recommended that the SARP plan for PS008 include in its funding an allowance to proactively renew electronic protection relays on a 15 year cycle. This is in addition to the current existing allowance for the renewal of problematic electromechanical relays.

In practice, relays and schemes will not be replaced based on age alone. The prioritisation of protection relays for selection will be based on a combination of factors which will be highlighted in the Statement of Asset Need. These factors include:

- The failure history and probability of failure of that relay or equipment.
- The failure mode.
- The impacts of the type of failure considering the location the relays are installed.
- The level of backup protection provided by other systems.
- Whether or not the relay has watchdog supervision and a failure alarm.
- Maintenance difficulties.
- The availability of spare relays or spare parts.
- The expertise available to properly maintain the scheme in the system.
- The ability to maintain setting software and firmware updates required to properly maintain the relay.
- Deficiencies in the current protection system.
- The overall quantity of the schemes and cost and impact of replacement.
- The enhanced opportunities provided by replacement:
  - Safety
  - Reliability
  - Cost to serve

1/12/14

Matthew Browne
Protection Manager

STATEMENT OF ASSET NEED

# DISTRIBUTION FEEDER PROTECTION MODERNISATION

## SARP PS012

November 2014

**Matthew Browne**

Protection Manager - Secondary Systems

Endeavour Energy

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# 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 cost of the program is estimated to be $27.9M (including contingency) over 9 years commencing in 2015/16 and the program covers 659 feeders across 70 zone substation sites. **This statement of asset need recommends that a business case be developed to gain approval for $6.4M, being $3.2M in each of the 2015/16 and 2016/17 years for the implementation of these works on 168 feeders across 15 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. The assessment suggests that this risk control would have to cost greater than $122M NPV 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 and bushfire ignition.** 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.
- **A lower risk of non-operation of feeder protection** due to duplication (bringing protection systems up to current standard). This has been assessed to be necessary to align to the design criteria in the National Electricity Rules and industry best practice, 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.

- 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).
- The ability to apply circuit breaker failure functionality, thus reducing the risk of uncleared faults as well as reducing the extent of reliability impact.
- 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 hazards are one of the most notable safety hazards in the electrical industry. There have been at least 6 persons injured (5 serious) within the last 4 years, and all of these accidents have occurred on the distribution network:

| Date | Location | Circumstances |
|---|---|---|
| 30/10/2013 | Eastern Creek | 2 x ASPs on fire and hospitalised with serious burns after they cut into a distribution feeder cable. |
| 24/10/2013 | Northmead | A member of the public was hospitalised with serious burns after he cut into a cable. |
| 07/2012 | Prestons | A member of the public received serious burns and was hospitalised at concord burns unit for 2 months after he cut into an HV cable on the end of a padmount substation. |
| 15/05/2012 | Kellyville | An employee was hospitalised with recoverable burns to his face and stomach after cutting into an HV distribution cable |
| 14/10/2010 | Penrith | An employee received serious bodily burns when he switched hazemeyer onto an existing cable fault. |

These incidents often lead to long and painful recover, lasting physical quality of life impacts, and a high incidence of post-traumatic stress. 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 distribution network within in the last 10 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. |

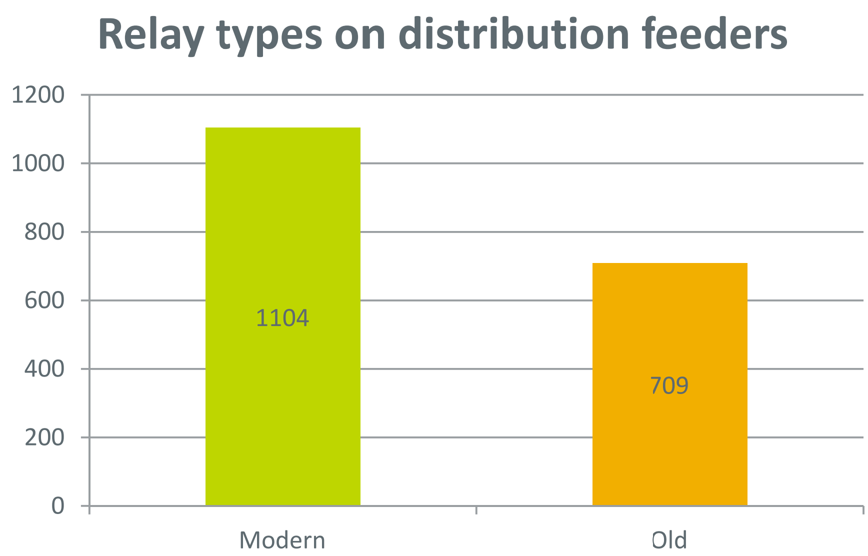
## 2.3 Modern technology and fault clearance

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:

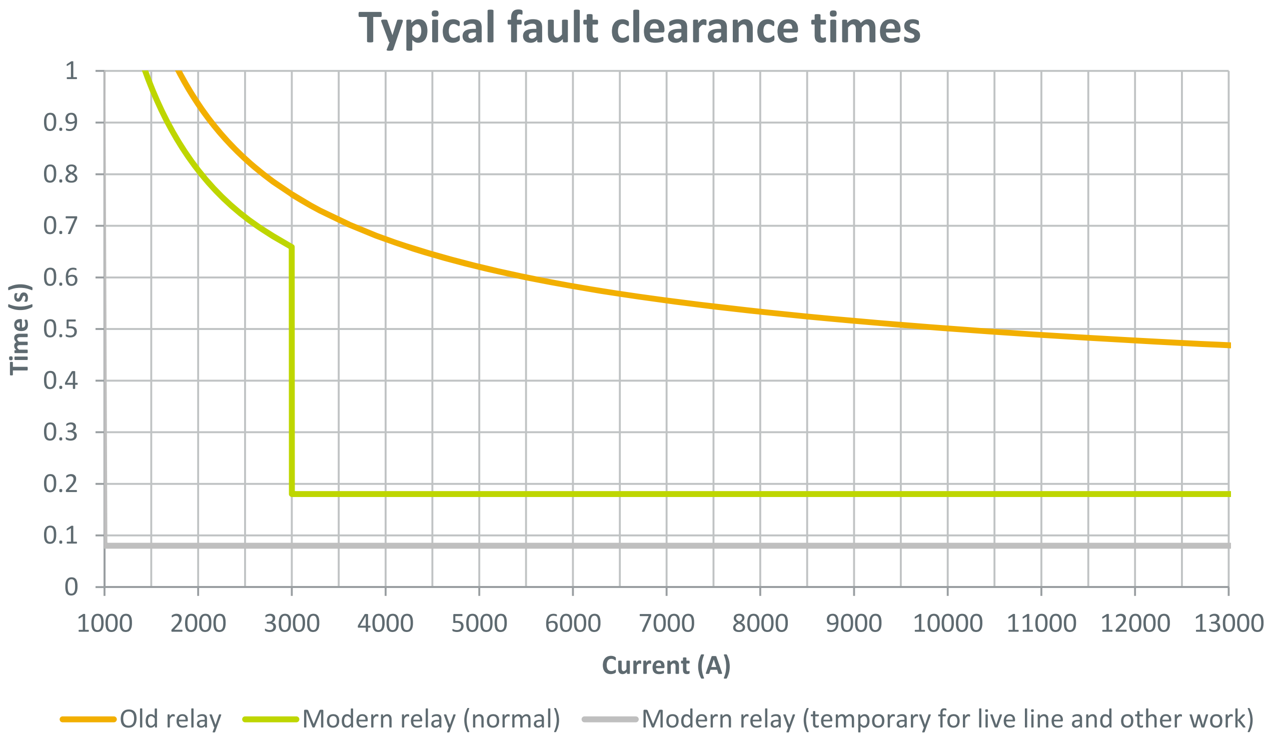
- multiple characteristic curve shapes;
- a more flexible time shift multiplier;
- a more accurate characteristic (e.g. trip, overshoot and reset times) resulting in the potential for a safe reduction in coordination margins, and most importantly;
- the ability to use high speed or instantaneous protection 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 1760 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.



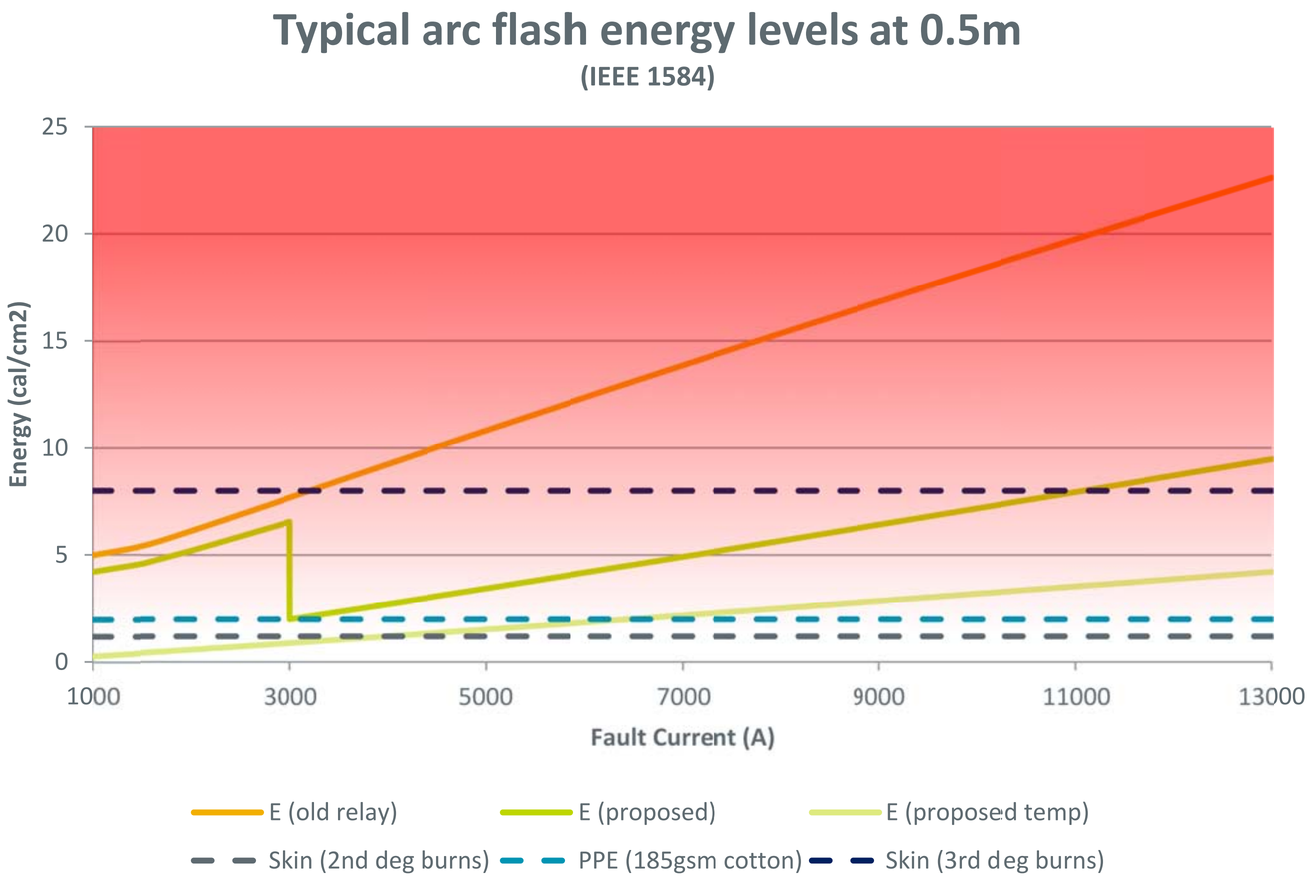

The graph below shows the substantial reduction in clearance time which can be achieved on a typical distribution feeder. Where the highset setting is included, the fault clearance time can typically be reduced by 60% to 85% for faults greater than 2-3kA. These higher fault levels, where the high-set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


Typical fault clearance times
Time (s)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
13000
Current (A)
Old relay
Modern relay (normal)
Modern relay (temporary for live line and other work)

## 2.4 Fault Clearance time as a mitigation control

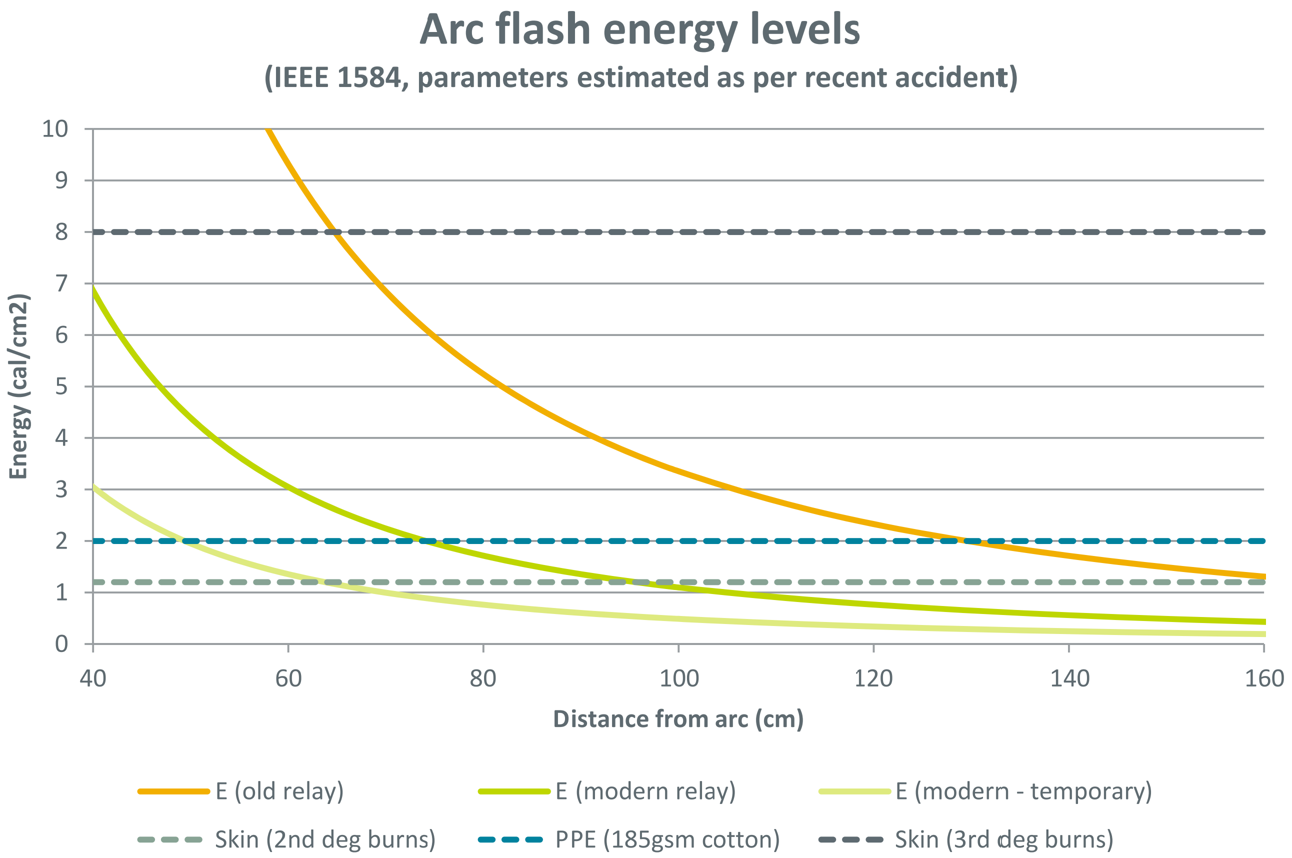
Fault clearance times are one of the key arc flash hazard controls listed in international best practice literature.

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.

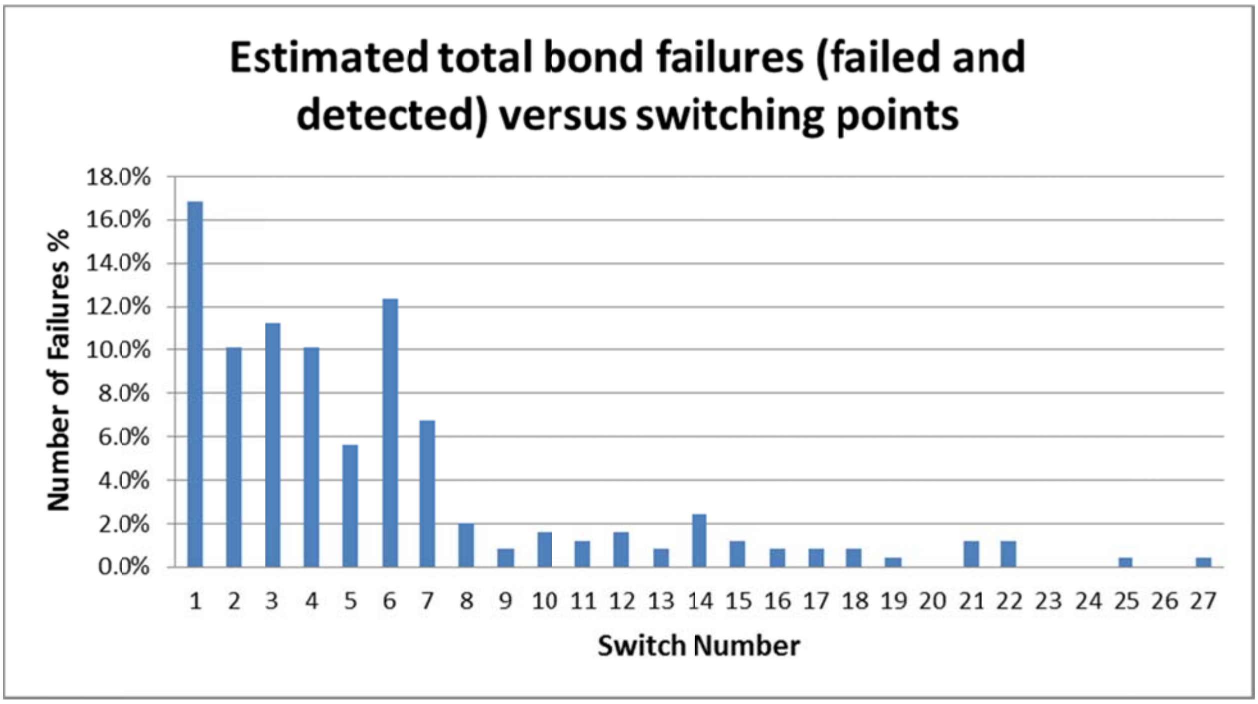
Some of these fault rating exceeded conductors can be adequately protected if modern relays are employed. It is estimated that $3.5 million worth of conductor replacements will be avoided through implementation of this program. Some of this cost saving has already been implemented by removal of work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

Regarding relay failure, the design criteria in National Electricity Rules (S5.1.9) says *… a Network Service Provider must provide sufficient primary protection systems and back-up protection systems (including breaker fail protection systems) to ensure that a fault of any fault type anywhere on its transmission system or distribution system is automatically disconnected ….*

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. 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%.

## 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.

## 4.0 CORE BALANCE CT'S AND HIGH RESISTANCE FAULTS

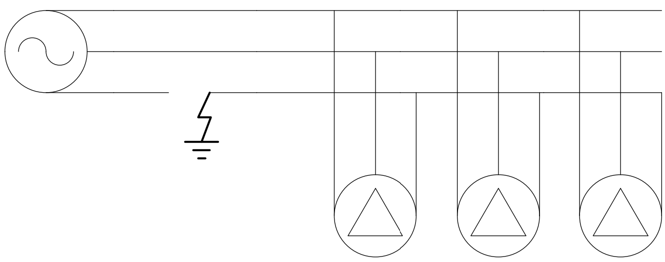
High voltage lines that remain energised on the ground carry with them a high risk of death or injury to individuals who make direct or indirect contact with the line. Both loss of life due to direct or indirect contact with a live downed conductor and loss of property due to fire have occurred on the 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.

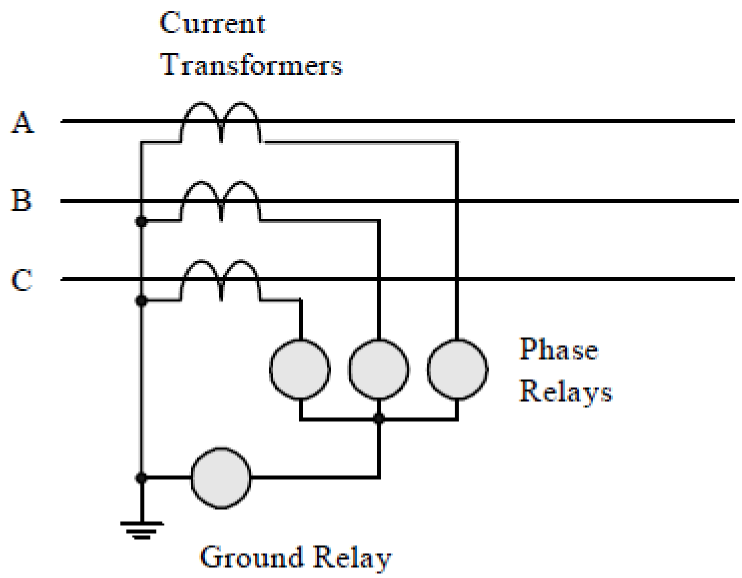
At the time of the incident, the estimated load current connected downstream of the fault was approximately 5A of primary current. Assuming no fault resistance and only constant impedance load, the calculated residual earth fault current in this case is 1.7A.

| | 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.

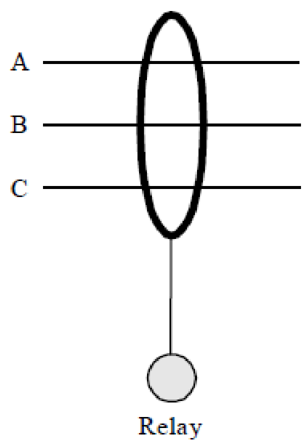
### 4.1.2 Residual current measurement

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 IMPLEMENTATION

There are 659 distribution feeder systems that require replacement under this project. Installations for which there is another approved SARP or SAMP project that will see the feeder protections replaced have not been included.

## 5.1 Prioritisation

Substations will be replaced based on a qualitative assessment of the following:

- Risk, including consideration of the following:
  - Underground systems and Arc flash energy
  - Overhead systems, earth resistivity and bushfire risks
  - The absence of sensitive earth fault protection
- Alignment with maintenance schedules
- Alignment with SCADA refurbishment projects
- Alignment with switchgear and other site refurbishment projects.

## 5.2 Site identification and changes

Identified sites have been included in Appendix A. Individual feeders will be identified in the project definition. Some changes to the site list will be required, for example:

- Site visits may identify inaccuracy in the Ellipse records, which have been used for this report.
- The cancellation or modification of approved SARP/SAMP projects may result in extra site requirements.
- New SAMP and SARP projects may result in the exclusion of works from this program.

These changes will be identified in the Project Definition or through a change control.

## 5.3 Project overlap

The remaining work to be done under PS009, namely the upgrade of existing SEF relays will be replaced in the near future by this project. It would make good business sense to cancel future PS009 works and expedite the implementation of PS012 at these sites instead. In 2014/15 $791k is allocated to PS009, and these funds can be reallocated to PS012. The SARP program PS009 can be permanently retired.

## 6.0 RECOMMENDATIONS

It is recommended that a business case be developed for the approval to spend $6.4M ($3.2M in each of the 2015/16 and 2016/17 years) to replace 168 of the identified distribution feeder protection systems and bring them up to current standard. In summary the upgrade consists of:

- Implement modern feeder protection systems as per current standards, including necessary SCADA system upgrades in order to accommodate remote control instantaneous protection as well as other benefits.
- Retrofit the core balance CT's where they can potentially feed overhead feeders in order to increase the potential sensitivity of protection systems to lines on the ground from approximately 4A to 1A or lower.
- Install circuit breaker failure systems to improve safety, compliance and reliability.

| **Prepared by** | **Endorsed by:** |
|---|---|
| 1/12/14 | 1/12/14 |
| Matthew Browne | Stephen Lette |
| Protection Manager | Manager Secondary Systems |

# 7.0 APPENDIX A (PRELIMINARY SITE LIST)

Ignoring incapable relays which will be replaced under alternative SAMP and SARP projects, there are 659 protection relays across 70 zone substations which require replacement. Those selected for the first two years have fault levels higher than 9kA, and have been ranked based on quantity of underground distance per feeder, given that underground network is responsible for the highest safety impacts.

| Site List | | | | | |
|---|---|---|---|---|---|
| Northern | | Central | | Southern | |
| Substation | Qty | Substation | Qty | Substation | Qty |
| Arndell Park | 10 | Ambarvale | 9 | Albion Park | 5 |
| Blackmans Flat | 6 | Anzac Village | 10 | Culburra | 2 |
| Blaxland | 11 | Appin | 4 | Huskisson | 5 |
| Cambridge Park | 9 | Berrima Junction | 5 | Inner Harbour | 10 |
| Cattai | 8 | Bonnyrigg | 13 | Kenny Street | 8 |
| Cranebrook | 10 | Bossley Park | 10 | North Wollongong | 7 |
| Dundas | 13 | Bow Bowing | 20 | Port Central | 5 |
| Emu Plains | 9 | Bringelly | 3 | Russell Vale | 3 |
| Glenmore Park | 9 | Cabramatta | 13 | Warilla | 6 |
| Glossodia | 6 | Camden | 14 | | |
| Greystanes | 13 | Carramar | 9 | | |
| Hazelbrook | 11 | Homepride | 9 | | |
| Kandos | 4 | Horsley Park | 9 | | |
| Katoomba | 10 | Kentlyn | 14 | | |
| Kellyville | 6 | Lennox | 14 | | |
| Kenthurst | 8 | Liverpool | 12 | | |
| Kingswood | 13 | Macquarie Fields | 13 | | |
| Kurrajong | 4 | Minto | 19 | | |
| Lithgow | 12 | Mittagong | 5 | | |
| Luddenham | 4 | Moorebank | 11 | | |
| Newton | 10 | Moss Vale | 7 | | |
| North Richmond | 8 | North Parramatta | 10 | | |
| North Rocks | 9 | Prestons | 12 | | |
| Northmead | 11 | Quarries | 10 | | |
| Plumpton | 14 | Sherwood | 13 | | |
| Portland | 4 | Woodpark | 8 | | |
| Prospect | 13 | | | | |
| Quakers Hill | 7 | | | | |
| Richmond | 5 | | | | |
| Riverstone | 8 | | | | |
| Rooty Hill | 13 | | | | |
| Seven Hills | 12 | | | | |
| Wentworth Falls | 4 | | | | |
| West Castle Hill | 22 | | | | |
| West Pennant Hills | 12 | | | | |
| Wisemans | 4 | | | | |
| **TOTALS** | **332** | | **276** | | **51** |
| **GRAND TOTAL = 659 RELAYS (70 SITES)** | | | | | |

(highlighted) **= To be completed 2015/16 & 2016/17**

## 8.0 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."***

## 9.0 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$^{o}$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]**



Endeavour Energy

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.

### 9.1.1 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.

### 9.1.2 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

### 9.1.3 Incident energy and burns

The degree of injury a subject 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
- project.

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 |

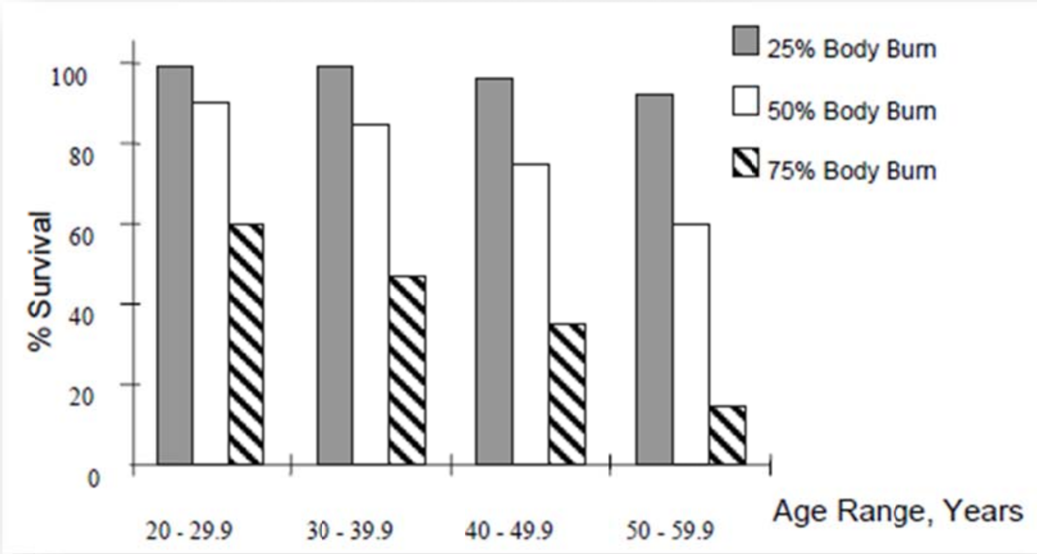
| | | | |
|---|---|---|---|
| | | | of body area.<br>Can ignite cotton clothing |
| Third | 8 | Extends fully into dermis | Scarring, contractures, amputation, can be fatal. |
| Fourth | | Extends through entire skin and into underlying fat, muscle and bone | Amputation, significant functional impairment, can be fatal. |

**2nd/3rd degree burns [3]**

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

### 9.1.4 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

# 10.0 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.

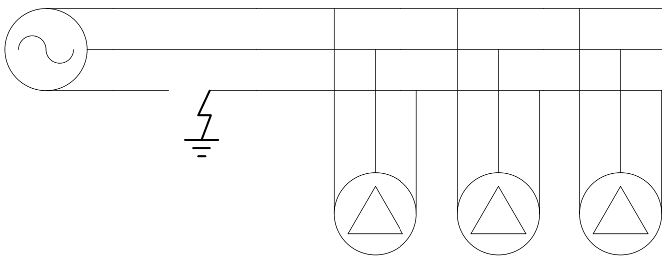


Endeavour Energy

# 11.0 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.

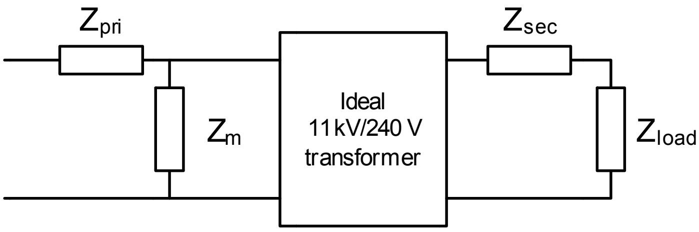


In these cases, even if fault resistance is low or zero, the fault current can be very low, and is primarily based on the impedance of the load connected to downstream transformers, as is illustrated by the technical analysis to follow.

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.



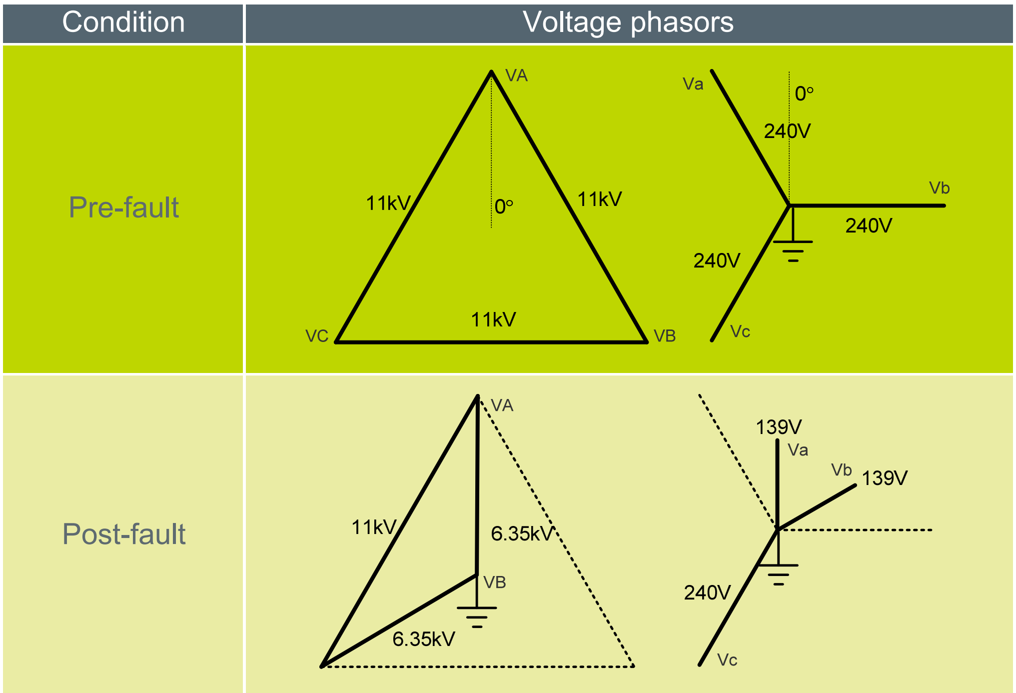
Endeavour Energy




| 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.

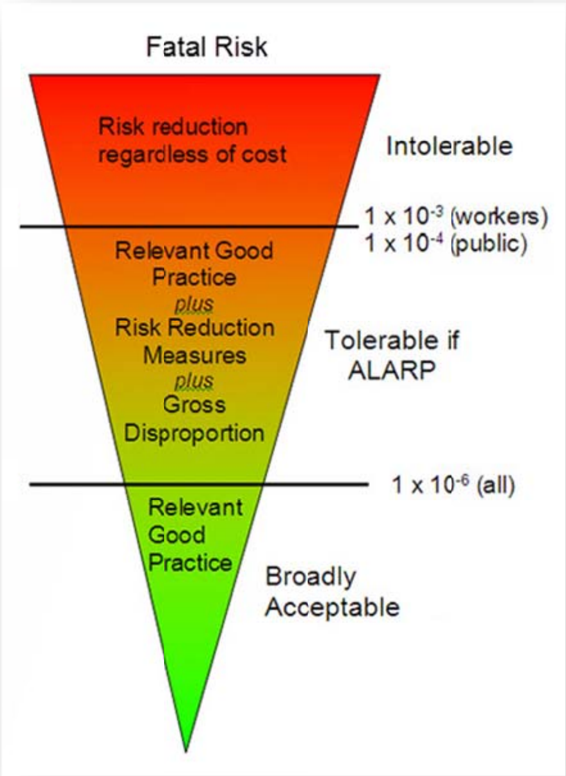



| | Pre-fault | | Post-fault | |
|---|---|---|---|---|
| | Magnitude | Angle | Magnitude | Angle |
| **VA** | 6351V | 0° | 6351V | 0° |
| **VB** | 6351V | -120° | 0V | 0° |
| **VC** | 6351V | 120° | 6351V | 120° |
| | | | | |
| **Va** | 240V | 30° | 139V | 0° |
| **Vb** | 240V | -90° | 139V | -60° |
| **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.

# 12.0 APPENDIX F (SAFETY COST BENEFIT ANALYSIS)

## 12.1 Modern relays - faster clearance times




### 12.1.1 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. 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.

### 12.1.2 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 $4.07M (in 2013), 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 in order 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) = $4.07M in 2013 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

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

$$= 4.07M\ \times (0.265)\ \times (0.441) \times \frac{1}{4\%}\left[1-\left(\frac{1}{104\%}\right)^{20}\right] \times 10 = \$\mathbf{122}\boldsymbol{M}\ NPV$$

Given these parameters, the NPV of the safety benefit, is $122M over the 20 year life of the relays.

### 12.1.3 Sensitivity analysis

Adjusting values to non-conservative levels:

| Impact | NPV ($M) |
|---|---|
| Frequency reduced to 0.5pa | 61 |
| Injury weighting factor for burns <20% of body (0.158) | 44 |
| Reduction in impact of control reduced to 0.2 | 41 |
| Disproportionate factor reduced to 3 | 37 |
| Life of control reduced to 10 years | 49 |

### 12.1.4 Summary

The value of the reduction in arc-flash injury has been calculated to be $122M 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 less 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 prior to consideration of other benefits of this project.

## 12.2 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.

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 $4.07M (in 2013), 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 in order 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) = $4.07M in 2013 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

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

$$= \$\mathbf{45.3M}\ NPV$$

Given these parameters, the NPV of the safety benefit, is $45.3M over the 40 year life. Given that the cost of the project is substantially less than the cost of the benefit of 2.7M ($2.2M 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.

### 12.2.1 Sensitivity analysis

Adjusting values within their band of tolerance:

| Impact | NPV ($M) |
|---|---|
| No changes | 45.3 |
| Frequency reduced to 1 in 50 years | 9.1 |
| Detection rate only increased by 5% (instead of 30%) | 7.6 |
| Detection rate increased to 70% (instead of 30%) | 106 |
| Life of control reduced to 20 years | 13.9 |
| Frequency rate reduced to 1 in 50 years, and detection rate only 10% | 3.1 |

### 12.2.2 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 $45M 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.

## 12.3 Circuit breaker failure protection

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.

# 13.0 APPENDIX G (BASIS FOR ALARP QRA)

### 13.1.1 Why use a quantitative assessment?

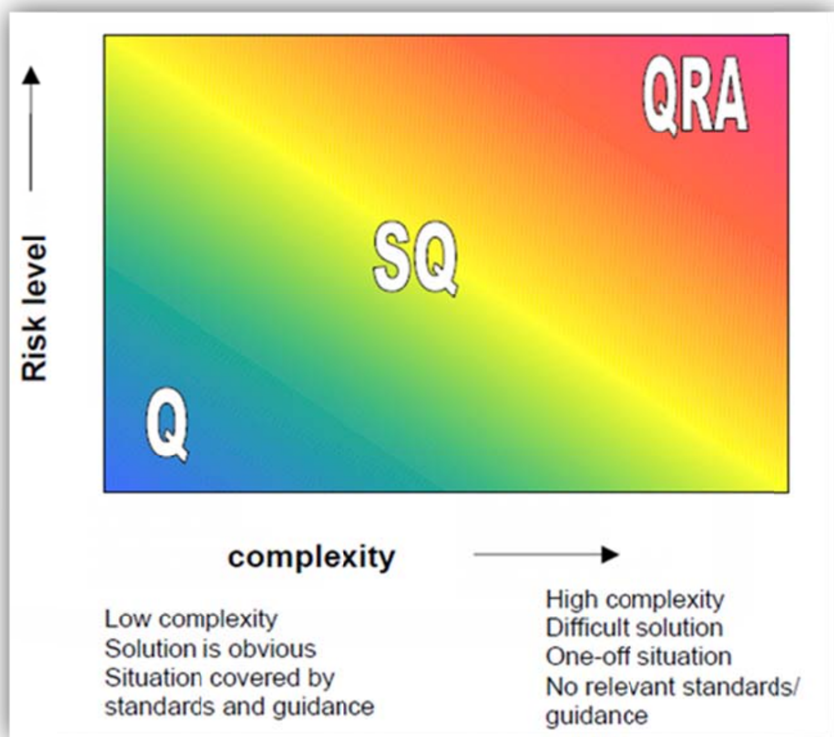
The NSW Work Health & Safety Act requires that risks be ALARP. If risks are not ALARP, people could be needlessly injured and the business and individuals liable for prosecution. However, the government and society also expects us to be efficient and effective. If money is spent on controls which are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

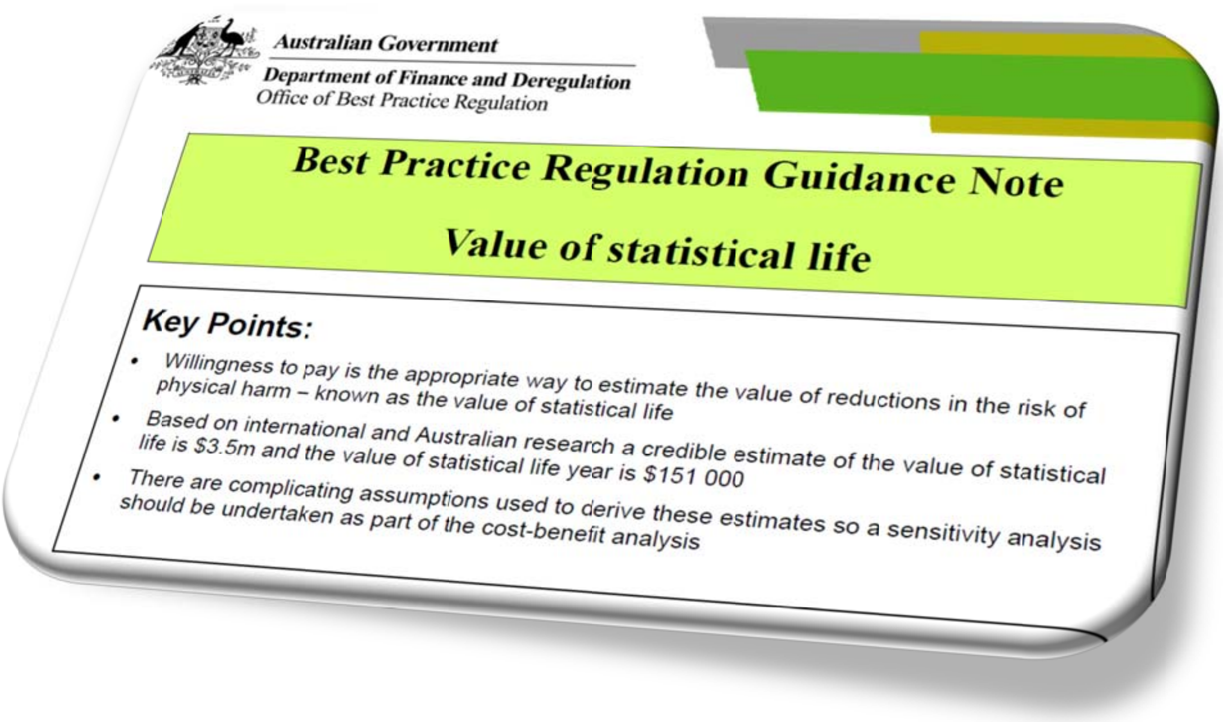
### 13.1.2 The value of a statistical life (VSL) in Australia

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 $4.07M (in 2013 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

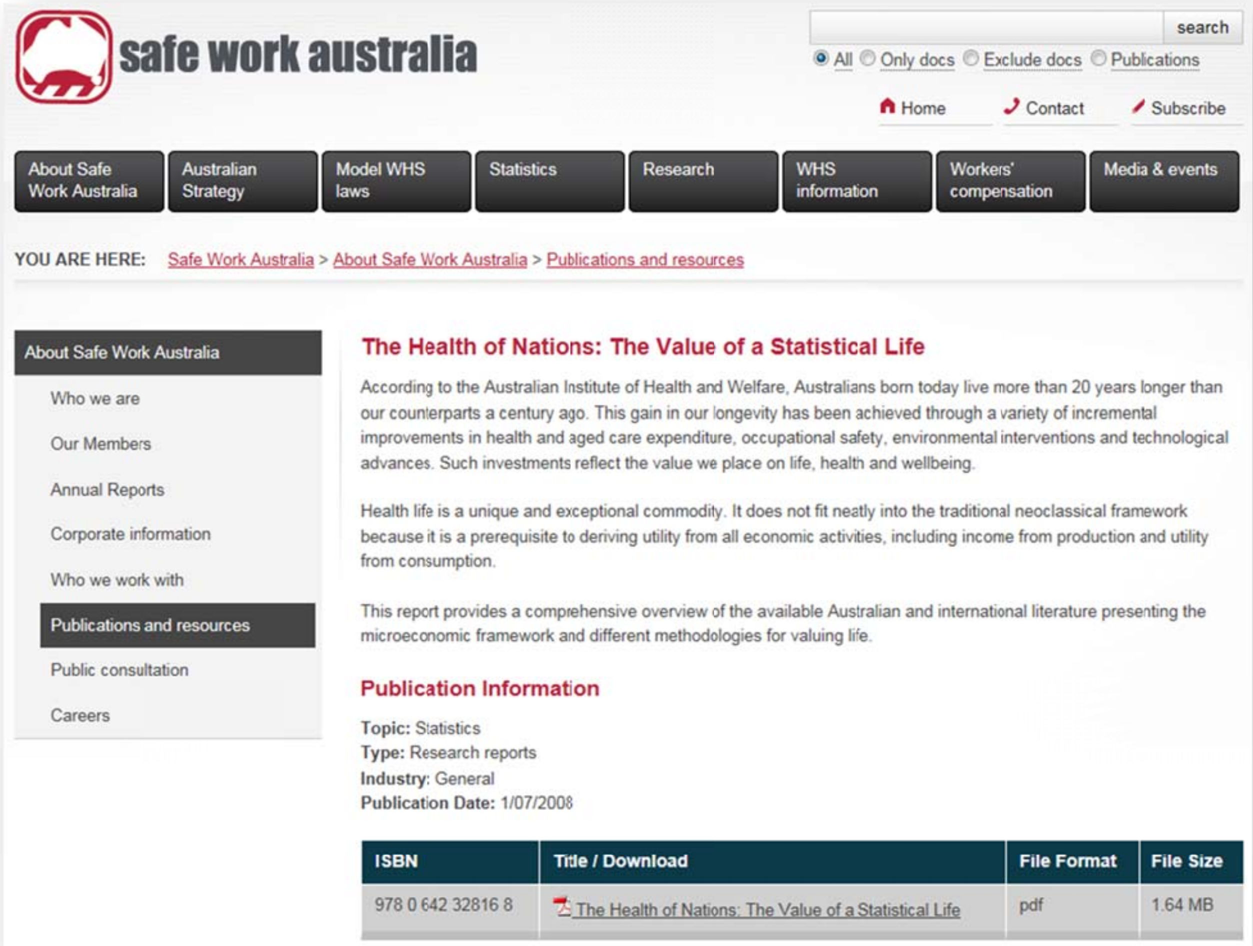
**Best Practice Regulation Guidance Note**

**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.




### 13.1.3 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 |

### 13.1.4 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.

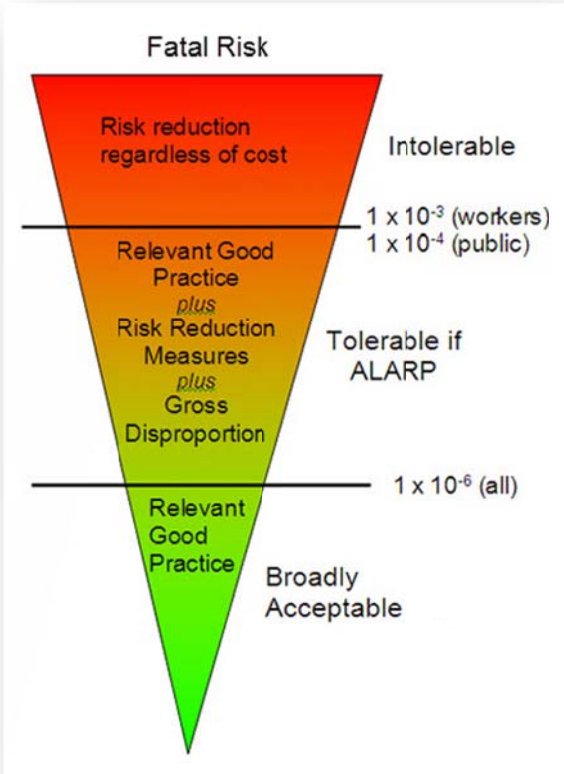
Victorian Government Guidance: *The ANCOLD (2003a) guidelines are based on HSE which indicates as generally reasonable a disproportionality factor of 10 for risks just below the Limit of Tolerability and dropping to approximately 3 for risks just above the broadly acceptable level. The HSE framework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

### 13.1.5 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**

#### 13.1.6 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

### 13.1.7 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.

### 13.1.8 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.

#### 13.1.9 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":

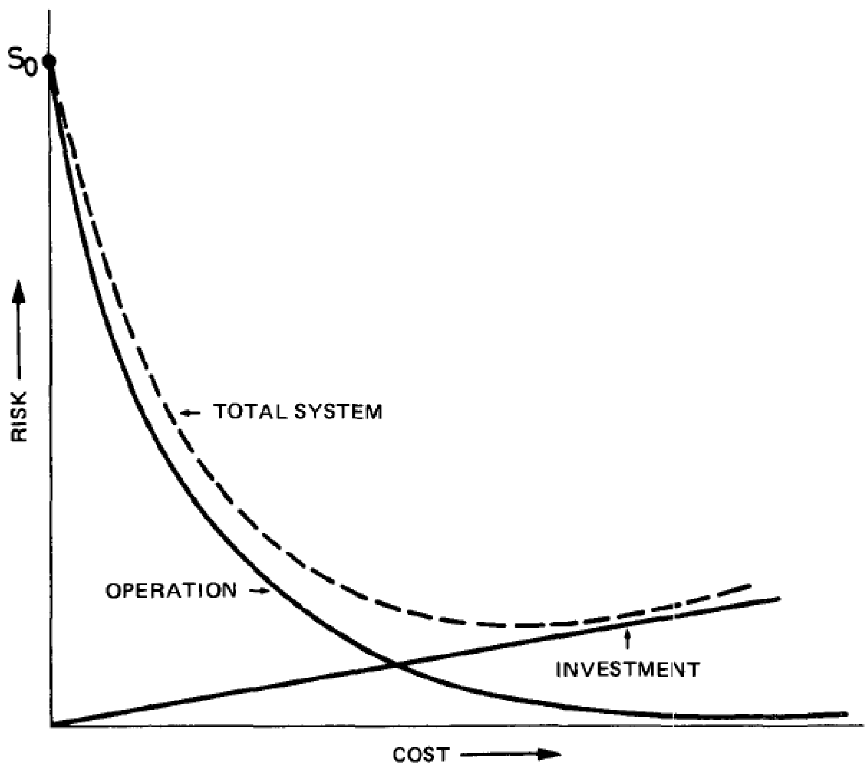



**FIGURE 2. Principal relationship of cost-effectiveness of risk reduction considering the total economic system.**

*"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."*

<u>Nichols says: (In "The Perils of Prudence")</u>

*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.*

<u>The paper "Redistributing risk" says:</u>

***…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) [link]

*'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.*

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

*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.*

<u>The cost of fire in Australia (Risk Frontiers, Macquarie University)</u>

*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.*

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# HARDEX PILOT CABLE RENEWAL
# Project TM013-03

*Business Case 2012/13*

**Revision 2.2**
19 July 2012

**Prepared:**

19/7/12

Jonathan Cook
Major Renewal Projects Manager

**Endorsed:**

24/7/12.

Ty Christopher
General Manager Network Development

**Reviewed and endorsed:**

Manoraj Jayasekara
Acting Manager Strategic Asset Management

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## 1.0 EXECUTIVE SUMMARY

The purpose of this business case is to seek approval for the replacement of the existing HARDEX pilots and earthwires on a number of 66kV and 33kV feeders with a combination of optical fibre ground wire (OPGW), all dielectric self-supporting optical fibre cable (ADSS) and underground optical fibre cable.

This document also updates the strategic direction of the program of replacement of HARDEX using a combination of OPGW, ADSS and underground optical fibre and the experience gained during the Smartgrid pilot program.

A number of facts have become apparent over the three years since the original HARDEX renewal strategy was endorsed and the initial business case was approved which point to the need for a revised strategy for the replacement of HARDEX:

- It has been confirmed through the installation of ADSS optical fibre cable within the network that ADSS is commonly available technology which can be provided quickly and cheaply by a number of service providers in a competitive commercial environment;
- OPGW is a more specialised technology which requires access to the electrical network. Accordingly, tenders from external service providers are significantly more expensive than the cost of carrying out the work using in-house resources;
- In-house staff resources are constrained and thus there are significant constraints on delivery of OPGW projects;
- All HARDEX will eventually need to be replaced, either with OPGW or with an aluminium earthwire.

Taking these factors into account has led to the development of a revised strategy for the replacement of HARDEX pilot wires. The proposed strategy is supported by the internal stakeholders and includes:

- Acceleration of the roll-out of ADSS to complete the optical fibre network to replace the communications functions of the majority of the HARDEX pilot wire systems in the area of Western Sydney in the short-term (during 2012/13);
- Completion of the optical fibre network utilising ADSS in the Blue Mountains, Macarthur, Wollongong and Port Kembla areas during 2013/14 and 2014/15;
- The continued installation of OPGW as the earthwire on all new and rebuilt feeders;
- The replacement of the remaining 400km of HARDEX earthwire with OPGW over time as internal resources become available to address the strength, fault-rating and earthing functionality shortcomings of HARDEX. Over the longer-term, this will provide for effective earthing and improved safety throughout the affected parts of the network as well as providing secure optical communications options beyond the life span of the ADSS optical links;
- There is an option to replace the HARDEX with a smaller earthwire or to remove the HARDEX and not replace it in sections, particularly on the some of the longer rural feeders. This approach will yield reduced program costs and but needs to be resolved over time in conjunction with earthing studies for the substations and lines in question.

The overall plan, which includes the completion of the roll-out of ADSS and the replacement of HARDEX earthwires with OPGW over a ten-year period, totals $110 million, including an allowance for CPI and contingencies and assuming that all of the installed HARDEX is replaced. Of that amount, it is estimated that $48 million will complete the replacement of the protection communications functions of the HARDEX with ADSS and replacement protection relays and the remaining $62 million (or less) will address the HARDEX earthwire replacement needs over the longer-term.

This business case seeks approval for a number of elements of the strategic plan to be carried out during the 2012/13 - 2014/15 years. The elements, including their estimated year of completion, are shown in the following table.

| | Works | 12/13 | 13/14 | 14/15 | 15/16 – 21/22 |
|---|---|---|---|---|---|
| **This business case** | Completion of previously approved works replacing HARDEX with OPGW | 509, 439, 446, 447 | 818, 493, 484, 470 | 435 | |
| | HARDEX and protection relay replacement + OPGW link installation on Feeder 825 | | 825 | | |
| | HARDEX earthwire replacement (with OPGW) on the first set of 33kV feeders | | | 774, 777, 779, 454, 456, 457, 459, 471, 472, 475 | |
| | ADSS and UG fibre rollout to complete fibre rings to provide for HARDEX protection pilot + relay replacement | Western Sydney | | | |
| **Future business case(s)** | ADSS and UG fibre rollout to complete fibre rings to provide for HARDEX and copper pilot protection pilot wire + relay replacements | | Macarthur & Blue Mountains | Wollongong – Port Kembla | |
| | HARDEX earthwire replacement (with OPGW or aluminium earthwire) on the remainder of the feeders currently fitted with HARDEX | | | | 48 feeders |

The plan to complete the optical fibre network in Western Sydney in the short-term will provide the benefits of ensuring the ongoing reliability of the protection systems on the 66kV and 33kV feeders which are currently provided by failing HARDEX pilot wires. Further secondary benefits include:

- Improved speed and reliability of the SCADA system controlling the network of zone and transmission substations. This should be particularly apparent during bad weather and emergency situations and lead to a reduction in unplanned outages.
- Provision of high speed communications between zone and transmission substations and the control centre and offices to enable the full potential of the intelligent relays and field devices currently being installed in the network to be realised. This will provide increased availability of data and hence facilitate improved operation, control and management of the network to assist maintain levels of reliability and safety as the network becomes increasingly complex.

The benefits provided by the longer-term plan to replace the HARDEX earthwires include:

- Addressing the safety risk presented by HARDEX earthwire burning down and falling to the ground during earth fault situations and due to corrosion damage and
- Improving the safety of zone and transmission substations by improving the earthing capability of the connected feeder earthwires which are currently fitted with HARDEX earthwire.

Accordingly, this business case seeks approval for the following expenditure:

- $6.06 million for the installation of OPGW optical fibre links on the 66kV Feeder 825 and associated optical fibre termination and protection works and for the replacement of the Hardex earthwires on 33kV feeders 774, 777, 779, 454, 456, 457, 459, 471, 472 and 475.
- A contingency sum of $0.91 million to cover unforeseen events, in particular the replacement of additional poles in the overhead sections and ducts in the underground sections of the above lines.
- An additional amount of funding for $4.74 million to complete the works of replacing

Hardex earthwire and pilot with OPGW approved in 2009;

- A contingency sum of $1.05 million to cover unforeseen events associated with the works previously approved, in particular the replacement of additional poles in the overhead sections and ducts in the underground sections of the lines;
- A capital expenditure of $14.08 million for the installation of ADSS and underground optical fibre links and associated optical fibre termination and protection works to complete the replacement of the communication pilot functions of the Hardex in Western Sydney;
- A contingency sum of $2.11 million to cover unforeseen events, in particular the replacement of additional poles in the overhead sections and ducts in the underground sections of the lines and modifications to the control buildings to accommodate the optical fibre termination and replacement protection equipment.

Thus this business case seeks approval for the total amount of $28.95 million, including contingency and CPI adjustments, to be expended during the 2012/13 – 2014/15 years.

Funding allocations for these works are included in SARP and SAMP programs TM01303, TM01302, SG001 and PS008 and cover the proposed expenditure.

## 2.0 INTRODUCTION

The purpose of this business case is to seek approval for the next stage of the program to replace HARDEX pilot wire/earthwires with a combination of optical fibre ground wire (OPGW) and all dielectric self-supporting optical fibre cable (ADSS) on 66kV and 33kV feeders throughout Endeavour Energy's network in accordance with the HARDEX Replacement Plan 2012[1].

The initial stage of this program was approved by the Chief Executive Officer in May 2009 and covered the replacement of HARDEX on 66kV Feeder 818 and 33kV feeders 493, 484, 509, 435, 439 and 473. Later, due to the failed condition of the HARDEX pilots on Feeder 470 from Seven Hills ZS to Marayong ZS, Feeder 470 was brought forward into the short-term program in place of Feeder 473. Further, in March 2011, the HARDEX on 33kV feeders 446 and 447 from Hawkesbury TS to Windsor ZS was approved for replacement with OPGW to support the earthing needs of the redeveloped Windsor ZS.

HARDEX consists of a pilot cable surrounded by stranded galvanised steel earthwire. It was installed as the earth wire on selected 33kV and 66kV sub-transmission feeders in the northern and central parts of Endeavour Energy's area. HARDEX serves both as the overhead earth wire and the communication pilot for the protection scheme for that feeder.

Over time, the pilot wires fail due to moisture ingress to joints and damage caused by lightning strikes, thus rendering the primary protection systems inoperable. The steel earthing conductors also corrode and fatigue increasing the risk of the earthwire falling. Furthermore, the fault rating of the HARDEX is inadequate for many parts of the network and in particular, for the first 33kV feeders out of the urban transmission substations. Thus there is a risk of the HARDEX burning down in the event of a fault occurring in a critical location.

On the basis of the above, it has been concluded previously that HARDEX throughout the network is not fit for purpose and is to be replaced by either OPGW or a combination of ADSS and aluminium earthwire in a planned manner over a number of years.

OPGW provides for both the communications and earthing needs whereas ADSS provides for only the communications needs.

The feeders for replacement have been prioritised based on their condition, exposure to high fault levels, criticality in the network and age.

This business case covers the next group of 66kV and 33kV feeders in the plan and includes feeders:

- 825 Carlingford TS – Castle Hill ZS
- 774 Guildford TS – Smithfield ZS
- 777 Guildford TS – Sherwood ZS
- 779 Guildford TS – Woodpark ZS
- 454 Penrith TS – Emu Plains ZS
- 456 Penrith TS – Cambridge Park ZS
- 457 Penrith TS – Kingswood ZS
- 459 Penrith TS – Cranebrook ZS
- 471 Baulkham Hills TS – Jasper Rd ZS
- 472 Baulkham Hills TS – North Rocks ZS
- 475 Baulkham Hills TS – Seven Hills ZS

[1] Hardex Renewal Plan, v3.0, Asset Renewal Planning Branch, 27 May 2009

The business case also includes the installation of a set of 37 ADSS links which will integrate with the existing and proposed OPGW and underground optical fibre links to essentially complete the optical fibre network in Western Sydney. This will allow the communications functions of the majority of the HARDEX links in Western Sydney to be decommissioned.

The expenditure for the OPGW works is estimated to total $12.76 million, including contingency and CPI adjustments, to be incurred over the 2012/13 to 2014/15 years. The expenditure for the ADSS works is estimated to total $16.19 million, including contingency, to be incurred during the 2012/13 year.

## 3.0 PROJECT NEED

The HARDEX cable operates as an earthwire, lightning shield wire and as the main communication pilot for the feeder's protection system. It is effective as a lightning shield wire but its performance as the earthwire is marginal and its use as the communications pilot is also problematic. The performance of HARDEX for each of these functions is described below.

### 3.1 Earth fault rating

As noted above, the steel armouring of the HARDEX is used as the feeder earthing conductor and has a fault rating of 3.6kA for 1 second.

The Endeavour Energy requirement for the earth conductor in sub-transmission lines is generally 26.2kA at 33kV and 13.1kA at 66kV for 1 second. As the rating for the HARDEX is substantially below these levels, its performance as an earthing conductor can only be considered to be marginal at best. Consequently the HARDEX is often not bonded to the substation earth grid at each end of the feeder (to protect it from high fault currents) and hence does not assist with the earthing of the substations.

Notwithstanding that the HARDEX is not bonded to the substation earthgrids, it can still be exposed to large magnitudes of fault current in some situations.

Generally, HARDEX is protected from damage due to excessive fault current by the fast operation of the unit protection schemes. However, instances of burn-down have occurred.

Recent incidences where the HARDEX has been exposed to earth fault current and has actually melted and fallen to the ground are shown in Table 1 below.

**Table 1 – Recent incidents of HARDEX burn-down**

| Feeder No. | From | To | Incident |
|---|---|---|---|
| 470 | Seven Hills ZS | Marayong ZS | Circa 2010, A flash-over from conductor to earth caused by a cockatoo caused the HARDEX to burn down. |
| 825 | Carlingford TS | Castle Hill ZS tee West Pennant Hills ZS | HARDEX was bonded to the Carlingford TS earthgrid and burned-down when conducting fault current from a fault on the feeder in 2011 |
| 456 | Mt Druitt TS | Cambridge Park ZS | 5 spans burnt down in the past. Pilot currently out of service. |
| 454 | Penrith TS | Emu Plains ZS | 4 Bays burnt down whilst conducting through-fault current during March 2012 |

## 3.2 Earthing performance

Not being connected to the substation earthgrids and the high resistance of the steel conductors limits the use of HARDEX for assisting the earthing of zone and transmission substations. This is particularly an issue for zone substations on small lots in residential areas.

Within the feeder itself, the high impedance of the HARDEX armouring renders it not particularly effective for limiting earth potential rise hazards in the event of earth faults. This is not a significant issue in wood pole lines but is a cause for concern for lines which use the more conductive concrete poles.

## 3.3 Mechanical failure

Over time the steel conductor part of the HARDEX corrodes and fatigues and can fail, causing the HARDEX to fall to the ground. The steel conductors can also be weakened by annealing after conducting excessive through-fault current (as noted above), leading to failure due to fatigue. A recent example of this was the failure of the HARDEX on Feeder 504 between West Liverpool TS and Moorebank ZS.

On October 2011, the HARDEX on Feeder 504 fell onto the 33kV mains causing a 33kV earth fault. Due to other works being undertaken at West Liverpool TS at the time, the fault caused an interruption to supply to customers connected to Moorebank and Anzac Village zone substations. The interruption lasted for approximately 90 minutes resulting in 1.05 million customer minutes lost and adding 1.2 minutes to Endeavour Energy's SAIDI indicator. The HARDEX also fell across the railway tracks causing interruption to peak-hour commuter rail services.

Thus the failure resulted in a serious incident for which a Significant Electricity Network Incident Advice (SENI) was required to be provided.

Whilst these circumstances were unusual, the failure of HARDEX due to corrosion and fatigue is not uncommon and supports the need for a program of replacement of the steel conductor part of the HARDEX system.

## 3.4 Lightning Shielding

A further function of the HARDEX is to provide lightning shielding for the feeder. The HARDEX is effective as a lightning shield and provides adequate protection for the feeder conductors provided adequate shielding angles are maintained as per Endeavour's standard feeder designs. However, the communication cores are prone to damage during lightning strikes as noted below.

## 3.5 Communication functions

Lightning strikes can cause an open circuit in the pilot cores mid-span and/or within the joint boxes. This is due to the fact that the insulation around the cores has inadequate impulse rating for exposure to lightning strikes. This is further compounded by its degradation with age and exposure to the elements.

This situation can be exacerbated by poor earth bonds at the joint boxes, which can cause the lightning strike voltage to be reflected and hence double its magnitude and thus further increase the electrical stress on the HARDEX pilot cores imparted from the initial strike. The pilot cores within the HARDEX are therefore not reliable in storm situations and there are a number of failed pilots within the network at any given time. Table 2 below lists the HARDEX which are currently failed. Refer Appendix C for further detail of the failures.

Note that when the pilot fails, the feeder is protected by back-up over-current and earth-fault protection relays. These operate more slowly than the pilot-wire system provided by the HARDEX thus exposing the network assets to higher levels of stress during faults and exposing both staff and the public to higher risks due to earth potential rise hazards.

**Table 2 – HARDEX circuits with failed pilots**

| Feeder No. | From | To | Incident/comments (System Operations) |
|---|---|---|---|
| 509 | West Liverpool TS | Homepride ZS | Defective pilot wires feeder 509 33KV pilot burnt down between poles #123 & 122 |
| 435 | Blacktown TS | Bossley Park ZS | Defective Pilot Wires Fdr 435 33kV Fdr 435 lockout |
| 470 | Seven Hills ZS | Marayong ZS | Defective pilots feeder 470 Translay pilot down into 11kv mains at pole 95 for one bay Fredrick St Blacktown. |
| 480 | Baulkham Hills TS | Northmead tee Northrocks ZS | Defective pilots fdr 480 Low IR reading on Fdr 480 - Baulkham Hills Z/S. |
| 487 | Mt Druitt TS | Plumpton ZS | Defective pilots Translay pilots defective due to primary fault adjacent to TS. |
| 755 | Guildford TS | Sherwood ZS | Defective pilots feeder 755 guildford Defective pilot ,FDR 755 Intertrip fault alarm |
| 456 | Penrith TS | Cambridge Park ZS | Pilot wires down feeder 456 Trip Fdr 456.AT Pole 701 bays of HARDEX Pilot wire down. |
| 825 | Carlingford TS | West Pennant Hills tee Castle Hill ZS | Defective pilots fdr 825 Trip FDR 825, Several bays of 66KV Mains down, 2 bays of pilots down pilot to be replaced back to T/S at Carlingford. |
| 454 | Penrith TS | Emu Plains ZS | Defective Pilot wires Fdr 454 Loss of Emu Plains ZS (lockout Fdrs 462 & 454 at Penrith) 4 bays pilot down Fdr 454 Castlereagh Rd cnr Andrews Rd - Pilots to be repaired. Possible cause previous lightning strike. |
| 516 | Liverpool TS | Moorebank ZS | Pilot Wire Failure Feeder 516 Pilot Wire Failure Feeder 516 Liverpool TS Pilot wire box corner ridge and Moorebank Ave damaged by birds structure 16 |

### 3.6 Summary of Need

The HARDEX pilot cables support critical high speed protection of the sub-transmission feeders.

In terms of the condition and performance of the HARDEX, information from the regional maintenance staff, supported by the examination of its earthing capabilities, suggests that the HARDEX is prone to failure during lightning strikes, particularly at the joints.

The available data indicates that the level of maintenance required to rectify the failures, although it appears to be not unreasonable, is significantly higher than required for other elements of the transmission network. Further, in some cases the process of locating and repairing emerging faults on a run of HARDEX can be a long and slow process and render the HARDEX pilots unserviceable for extended periods of time.

Thus there are ongoing problems with HARDEX cables and given its age and poor performance at best, there is a need to continue to the current program of replacement of those assets.

There is also need to ensure reliability of the high speed unit protection schemes supported by the HARDEX pilots particularly at critical sites with embedded generation such as Guildford Transmission Substation.

Most of the feeders with failed HARDEX have now been approved for replacement of their HARDEX and thus the program turns to the second part of the original strategy, which is to target feeders emanating from critical transmission substations, followed by the remainder of the HARDEX fleet over a period of ten years or so.

### 3.7 Coordination with the Smartgrid program

The Smartgrid program seeks to build a network of optical fibre interconnecting all of Endeavour Energy's zone and transmission substations, depots and offices. The topology includes a series of interconnected optical fibre rings using the low-cost all dielectric self-supporting (ADSS) optical fibre technology which is generally strung under the mains.

A pilot project in the Hawkesbury is now complete and a second sub-system of optical fibre, which closes up several partially complete rings, is currently under construction[2].

The termination equipment and communications protocols are common across all of the optical fibre links being developed in Endeavour Energy's area and thus there will be an integration of Smartgrid, OPGW and underground optical fibre into Endeavour Energy's optical fibre network.

The HARDEX renewal plan and this business case proposes to use the technology and installation techniques which have been demonstrated to be effective and efficient by the Smartgrid pilot program and in conjunction with strategic application of OPGW, to complete the optical fibre network and so allow for the decommissioning of the failing HARDEX-based protection communications system.

Although the primary purpose of the optical fibre network will be to provide for the protection systems which protect the network feeders and substations, it will also provide the following benefits:

- Improvement in the speed and reliability of the SCADA communications from the connected zone and transmission substations to the control centre(s). Currently SCADA utilises radio based communications links which have limited bandwidth and experience reliability problems, particularly in bad weather when availability of the control systems for emergency switching of the network is most critical;
- Improvement in the operation, control and management of the network. The current radio based communications system does have the capacity to convey all of the information from existing substation and field based devices which limits the information available for operation, control and management of the network. The proposed optical fibre network will remove these constraints and will allow the intelligent numeric relays and devices currently being installed in the network to be used to their full potential.

The roll-out of the Smartgrid pilot network to date has principally utilised ADSS technology with short lengths of underground optical fibre into substations and in locations where there are no overhead feeders available suitable to accommodate the ADSS.

The projects to date have provided experience which has been taken into account in planning for the renewal of the remainder of the HARDEX system. Notable influences on the development of a strategy for renewing HARDEX include:

- ADSS is commonly available technology which can be provided cheaply by a number of service providers in a competitive commercial environment. Being installed below the mains it can also be installed quickly and with little risk of contingency cost increases;

[2] Project SG001 – Fibre and MPLS Communications, Business Case 2011/12. Network Technology Strategy Branch, 22 February 2012.

- OPGW is more specialised technology which requires access to the electrical network.  Thus there are significant risks of delay and accordingly, tenders from external service providers are significantly more expensive than the cost of carrying out the work using in-house staff resources;
- However, internal resources are currently constrained and as result, delivery of OPGW projects are constrained;
- Further, ADSS is significantly less expensive to install than OPGW.  The installation of ADSS is currently about 25% of the cost of the installation of OPGW on a per kilometre basis;
- OPGW is however, more secure and has a longer life than ADSS;
- All HARDEX will eventually need to be replaced, either with OPGW or with an aluminium earthwire[3];
- OPGW has been provided on all new overhead transmission feeders (and an underground optical fibre provided with all new underground transmission cables) installed in Endeavour Energy's network in the past 5 or so years.

## 4.0 HARDEX AND PILOT REPLACEMENT STRATEGY

The replacement strategy for HARDEX was originally developed in the HARDEX Renewal Plan 2009 which was endorsed by the IGC and Chief Executive Officer in May 2009.  The strategy included the replacement of all HARDEX, which was currently in use, with either OPGW or ADSS.

At the time of endorsing the plan, the IGC acknowledged the lower cost of installation of ADSS and requested that a report be prepared recommending whether OPGW or ADSS should be adopted as the standard for replacing pilot cables, after experience gained installing and operating ADSS and OPGW systems.

After observing the installation of ADSS and OPGW systems over the past two years it can be confirmed that ADSS can be installed at significantly lower cost and significantly more rapidly than OPGW and thus lends itself to rapid and flexible deployment for broadband communication services.

Furthermore, any concern of inherent lack of reliability of ADSS system, due to its installation below the mains and susceptibility to damage in the event of fire, can be addressed by two significant facts:

1) The copper pilot system used in Southern Region and particularly around the Wollongong – Port Kembla area is installed below the low voltage feeders and has provided reliable service for in excess of forty years.

   There have been incidents of the pilots being brought down by high vehicles, but it is considered that ensuring appropriate clearances across major roads and intersections and or undergrounding the optical fibre in strategic locations effectively addresses this risk.

2) The optical fibre will generally form rings with redundant paths which allows for re-routing on loss of a leg of the ring.  Thus the fibre will essentially will provide an N-1 or better level of security for the protection systems using the optical fibre for communications. This is significantly better security than currently provided by the HARDEX based feeder

[3] Some of the longer feeders in the more rural areas may not require the overhead earthwire function of the HARDEX to be replaced over the entire length of the feeder.  However, this will need to be assessed on a case by case basis taking into account the earthing needed to ensure the safe operation of the substations at each end of the feeder(s).

unit protection schemes but is considered to be an appropriate level of security given that each optical fibre cable may carry protection signals for multi feeders.

Furthermore, the optical fibre protection relays also provide a distance protection scheme and thus continue to protect the feeder even after loss of the communications link.

Thus it is confirmed that ADSS is a suitable medium for carriage of network protection signals for 33kV and 66kV feeders.

Thus far, all plans for provision of optical fibre communications for protection of the 132kV network utilise OPGW or underground optical fibre for the communications links. There are currently no plans to introduce ADSS into these systems and this is considered to be an appropriate approach given the increased requirements for protection system performance at 132kV.

On this basis it is proposed that:

1) ADSS be used generally for provision of optical fibre communications between substations to replace the protection communications functions of the HARDEX systems (as well as be available for engineering and other corporate communications needs);
2) OPGW should be installed on all new and rebuilt feeders to provide for effective earthing as well as secure optical communications options for the longer-term, beyond the lifespan of ADSS;
3) OPGW should continue to be utilised for the high security 132kV protection systems (as is currently the practice) i.e. OPGW and or underground optical fibre should used for the remainder of the 132kV UPC replacement program TM01301 as is planned;
4) The remaining HARDEX earthwires should be replaced over time with aluminium earthwire as required to address their strength, fault-rating and earthing functionality shortcomings. Alternatively, if there is little cost difference between installing OPGW compared to aluminium earthwire (and at present this appears to be the case), then the earthwire should be OPGW. The OPGW optical fibres could be terminated if required or simply left sealed but unterminated for use in the future;
5) The HARDEX replacement with earthwire should be undertaken under program TM01303, rather the earthwire program TM017.

### 4.1 Ongoing HARDEX replacement program

Applying these principals gives the limited program of replacement of HARDEX with OPGW for communications as well as earthing purposes over the next two years, as shown in Table 3 below. Table 3 also includes the HARDEX previously approved for replacement with OPGW and HARDEX which is proposed to be replaced with OPGW for provision of communications and earthing functions in the future.

Note that the estimates in Table 3 include an allowance for annual CPI increases.

**Table 3 - Hardex – OPGW replacement plan**

| Fdr No. | From | To | Estimated cost ($000 of that year) 12/13 | 13/14 | 14/15 | 14/15 - 20/21 | Comments |
|---|---|---|---|---|---|---|---|
| 818 | Carlingford TS | West Pennant Hills ZS | | 630 | | | Approved 2009, TM01303 |
| 493 | Mt Druitt TS | Werrington ZS | | 310 | | | Approved 2009, TM01303 |
| 484 | Baulkham Hills TS | Jasper Road ZS | | 820 | | | Approved 2009, TM01303 |
| 470 | Seven Hills ZS | Marayong ZS | | 740 | | | Approved 2009, TM01303 |
| 509 | West Liverpool TS | Homepride ZS | 140 | | | | OPGW installed 2011, only underground fibre section to be installed during 2012/13 |
| 435 | Blacktown TS | Bossley Park ZS | | | 1,800 | | Approved 2009, TM01303 (5.1km OH, inc new ducts for 1.6km U/G) |
| 439 | Hawkesbury TS | Glossodia ZS | 1,620 | | | | Approved 2009, TM01303 (13.3km OH) |
| 446 | Hawkesbury TS | Windsor ZS | 465 | | | | Approved 2011,TM01303 |
| 447 | Hawkesbury TS | Windsor ZS | 465 | | | | Approved 2011, TM01303 |
| 825 | Carlingford TS | Castle Hill Tee WPH | | 950 | | | Failed and restrung early 2012. To be replaced with OPGW to support the redevelopment of Castle Hills ZS TS127 (5.7km OH, 2.8km UG, 80m new ducts) |
| 830 | Kenthurst ZS | Castle Hill ZS | | | | 1,640 | Kenthurst ZS is remote and not attractive in the short-term to Smartgrid roll-out. Replace HARDEX with OPGW fibre link in the future as noted. |
| 476 | Kenthurst ZS | Kellyville TS | | | | 1,240 | As above |
| **Total for HARDEX replacement with OPGW, 2012/13 onwards ($M)** | | | **2.69** | **3.45** | **1.80** | **2.88** | |

Table 4 provides a program for the replacement of the HARDEX on the remainder of the feeders with an aluminium earthwire (or OPGW) on the overhead sections and underground optical fibre and earth conductor with the cable sections, over a period of time. The total length of these feeders is approximately 400km.

The feeders are prioritised based on their known condition and history of failure and burn-down. Those projects which are currently in the design phase (based on earlier revisions of the HARDEX Replacement Plan) have been given priority.

The estimated costs assigned to these projects are based on the installation of OPGW for the earthwire, which is currently within 10% of the cost of the installation of an all-aluminium earthwire.

As noted above, it is expected that the costs of some of the longer feeders will be able to be reduced substantially by scaling back the replacement earthwire size and installing a small aluminium or ACSR earthwire in place of OPGW or deleting sections of the earthwire altogether once the earthing needs of each feeder and their associated substations have been are assessed.

## Table 4 - Hardex earthwire replacement plan (covering all remaining feeders with Hardex fitted)

| Fdr No. | Location | | Estimated cost ($000 of that year) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | From | To | 13/14 | 14/15 | 15/16 | 16/17 | 17/18 | 18/19 | 19/20 | 20/21 | 21/22 |
| 825 | Carlingford TS | Castle Hill tee West Pennant Hills ZS | 950 | | | | | | | | |
| 774 | Guildford TS | Smithfield ZS | | 520 | | | | | | | |
| 777 | Guildford TS | Sherwood ZS | | 300 | | | | | | | |
| 779 | Guildford TS | Woodpark ZS | | 450 | | | | | | | |
| 454 | Penrith TS | Emu Plains ZS | | 670 | | | | | | | |
| 456 | Penrith TS | Cambridge Park ZS | | 630 | | | | | | | |
| 457 | Penrith TS | Kingswood ZS | | 480 | | | | | | | |
| 459 | Penrith TS | Cranebrook ZS | | 660 | | | | | | | |
| 471 | Baulkham Hills TS | Jasper Road ZS | | 490 | | | | | | | |
| 472 | Baulkham Hills TS | North Rocks ZS | | 550 | | | | | | | |
| 475 | Baulkham Hills TS | Seven Hills ZS | | 360 | | | | | | | |
| 477 | Baulkham Hills TS | Westmead ZS | | | 640 | | | | | | |
| 478 | Baulkham Hills TS | Northmead ZS | | | 280 | | | | | | |
| 479 | Baulkham Hills TS | Seven Hills ZS | | | 360 | | | | | | |
| 755 | Guildford TS | Sherwood ZS | | | 500 | | | | | | |
| 756 | Guildford TS | Comalco T Yennora | | | 470 | | | | | | |
| 757 | Guildford TS | Cabramatta ZS | | | 990 | | | | | | |
| 759 | Guildford TS | Yennora ZS | | | 460 | | | | | | |
| 426 | Blacktown TS | Greystanes ZS | | | 630 | | | | | | |
| 830 | Kenthurst ZS | Castle Hill ZS | | | 1,640 | | | | | | |
| 430 | Blacktown TS | Greystanes T Woodpark | | | | 840 | | | | | |
| 432 | Blacktown TS | Holroyd ZS | | | | 700 | | | | | |
| 440 | Blacktown TS | East Prospect ZS | | | | 870 | | | | | |
| 445 | Blacktown TS | Marayong ZS | | | | 1,010 | | | | | |
| 450 | Blacktown TS | Doonside T Newton T Quakers Hill ZS | | | | 1,620 | | | | | |
| 503 | West Liverpool TS | Bonnyrigg ZS | | | | | 640 | | | | |
| 504 | West Liverpool TS | Moorebank ZS | | | | | 1,370 | | | | |
| 508 | West Liverpool TS | Liverpool ZS | | | | | 770 | | | | |
| 512 | West Liverpool TS | Kemps CK T Bringelly ZS | | | | | 3,320 | | | | |
| 514 | West Liverpool TS | Bonnyrigg ZS | | | | | 820 | | | | |
| 517 | West Liverpool TS | Homepride T Cabramatta | | | | | | 1,400 | | | |
| 487 | Mt Druitt TS | Plumpton ZS/Whalan | | | | | | 910 | | | |
| 451 | Penrith TS | Cranebrook ZS | | | | | | 1,350 | | | |
| 461 | Penrith TS | Kingswood ZS | | | | | | 730 | | | |
| 462 | Penrith TS | Emu Plains ZS | | | | | | 480 | | | |
| 488 | Mt Druitt TS | Plumpton ZS | | | | | | 610 | | | |
| 489 | Mt Druitt TS | Horsley Park East Wallgrove SS Horsley Pk | | | | | | 1,150 | | | |
| 491 | Mt Druitt TS | St Marys ZS | | | | | | | 450 | | |
| 492 | Mt Druitt TS | Werrington ZS | | | | | | | 320 | | |
| 495 | Mt Druitt TS | Whalan ZS | | | | | | | 630 | | |
| 496 | Mt Druitt TS | Werrington ZS | | | | | | | 270 | | |
| 469 | Jasper Rd ZS | Kellyville ZS | | | | | | | 1,190 | | |
| 745 | West Wetherill Park TS | Bossley Park T Smithfield | | | | | | | 1,780 | | |
| 444 | Hawkesbury TS | Riverstone ZS | | | | | | | 1,010 | | |
| 452 | Hawkesbury TS | Nth Richmond ZS T Richmond ZS | | | | | | | 3,610 | | |
| 476 | Kenthurst ZS | Kellyville TS | | | | | | | | 1,240 | |
| 453 | Hawkesbury TS | Nth Richmond T Kurrajong | | | | | | | | 2,450 | |
| 458 | Hawkesbury TS | Riverstone T Cattai ZS | | | | | | | | 260 | |
| 473 | Baulkham Hills TS | Kellyville / Marayong ZS | | | | | | | | 1,880 | |
| 522 | Bonnyrigg ZS | Canley Vale ZS | | | | | | | | 610 | |

| Fdr No. | Location | | Estimated cost ($000 of that year) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | From | To | 13/14 | 14/15 | 15/16 | 16/17 | 17/18 | 18/19 | 19/20 | 20/21 | 21/22 |
| 438 | Hawkesbury TS | Richmond ZS | | | | | | | | 930 | |
| 452/1 | Hawkesbury TS | North Richmond ZS | | | | | | | | 420 | |
| 497/1 | ABS | Simsmetal | | | | | | | | 390 | |
| 424 | North Richmond ZS | Kurrajong T Glossodia | | | | | | | | 2,460 | |
| 437 | Cattai ZS | Wisemans ZS | | | | | | | | | 2,860 |
| 465 | Warragamba ZS | Luddenham ZS | | | | | | | | | 2,980 |
| 846 | Nepean TS | Blue Circle Southern Cement | | | | | | | | | 100 |
| 847 | Nepean TS | " | | | | | | | | | 90 |
| **Totals ($M)** | | | **0.95** | **6.91** | **5.97** | **5.04** | **6.92** | **7.37** | **9.26** | **10.63** | **6.03** |
| **Total program ($M)** | | | | | | | | | | | **57.6** |
| **Total beyond current approved projects ($M)** | | | | | | | | | | | **48.2**[4] |

**Table 4 notes:**

The estimates in Table 4 include CPI increases of 3% per annum.

Refer Hardex Renewal Plan spreadsheet[5] for detail of the cost components of the works proposed for each feeder.

### 4.2 ADSS HARDEX replacement program

After consideration of the implications of the above strategy, a revised plan for the continuing roll-out of ADSS optical fibre to replace the communications functions of the HARDEX has been developed with the team who have been developing the SmartGrid concepts. The program, which will address the network protection needs in the area of Western Sydney in the 2012/13 year is detailed in Table 5 below. It is proposed that further stages of the roll-out of ADSS will include the Blue Mountains, Macarthur and Wollongong – Port Kembla areas in the 2013/14 and 2014/15 years. These will be addressed by a separate business case to be prepared during the 2012/13 year, when details of the protection services requiring replacement and the available routes have been further assessed.

Table 6 below shows the proposed ADSS and underground optical fibre roll-out plan for 2012/13 showing the principle purpose of each link proposed.

Table 7 below shows a breakdown of the cost elements of the optical fibre installations shown in Table 5 above. Refer Project SG001 – Fibre and MPLS Communications Business Case 2011/12[6] for further information.

[4] This is the maximum amount and is likely to decrease once the specific needs of each feeder are assessed on a case by case basis.
[5] Hardex Renewal Plan spreadsheet (v12, 5-07-12), Strategic Asset Management Branch, July 2012
[6] Project SG001 – Fibre and MPLS Communications Business Case 2011/12, Network Technology Strategy Branch, 22 February 2012

**Table 5 – ADSS and underground optical fibre roll-out plan for 2012/13**

| Optical fibre route | Locations | | Route length (km) | Cost estimates ($) | | | |
|---|---|---|---|---|---|---|---|
| | From | To | | Fibre | Term. | Totals | Principal purpose of the optical fibre link |
| 456 | Penrith TS | Cambridge Park ZS | 5.20 | 121,700 | 223,900 | 345,600 | OF to Cambridge Park ZS for protection of fdrs 456 and 497 |
| 473 | Kellyville ZS | Parklea ZS | 3.81 | 89,070 | 223,900 | 312,970 | OF to Kellyville ZS for protection of feeders 473 and 469 |
| 426 | Blacktown TS | Greystanes ZS | 5.27 | 95,890 | 223,900 | 319,790 | OF to Greystanes ZS for protection of Feeder 426 |
| 430 E and F | Greystanes ZS | Woodpark ZS | 2.32 | 39,440 | 223,900 | 263,340 | For protection of Feeder 430 and to close ring for protection 426, 430 and 779 |
| 779 | Woodpark ZS | Guildford TS | 3.69 | 62,730 | 156,000 | 218,730 | OF to Woodpark ZS for protection of Feeder 779 |
| 777 | Guildford TS | Sherwood ZS | 2.76 | 46,920 | 223,900 | 270,820 | OF to Sherwood ZS for protection of fdrs 777 and 755 |
| 757 (oos) | Smithfield ZS | Canley Vale ZS | 4.78 | 81,260 | 223,900 | 305,160 | Close ring for protection of feeders 757, 763, 745 and 774 |
| 522 | Canley Vale | Bonnyrigg ZS | 4.66 | 178,220 | 223,900 | 402,120 | Close ring for protection of fdrs 503, 514, 522, 523 |
| 745 | West Wetherill Pk ZS | Bossley Pk ZS | 3.16 | 86,120 | 223,900 | 310,020 | OF to Bossley Park ZS for protection of feeder 745 |
| 503 | Bonnyrigg ZS | West Liverpool TS | 5.02 | 102,440 | 156,000 | 258,440 | OF to Bonnyrigg ZS for protection of feeder 503 |
| 759 part | Fairfield ZS | Yennora ZS | 2.62 | 44,540 | 223,900 | 268,440 | OF to Yennora ZS for protection of fdrs 756 and 759 |
| LV | Yennora ZS | Carramar ZS | 2.90 | 76,300 | 223,900 | 300,200 | OF to Carramar ZS and Close ring for protection of fdrs 756, 759, 671, 672, 673, 674, 757,517 |
| LV | Carramar ZS | Cabramatta ZS | 2.95 | 151,850 | 223,900 | 375,750 | Close ring for protection of fdrs 756, 759, 671, 672, 673, 674, 757,517 |
| 517 (new 68C) | Cabramatta ZS | Homepride ZS | 3.92 | 66,640 | 156,000 | 222,640 | OF to Cabramatta ZS for prot. of fdrs 517 (68C) and 757 |
| 432 | Blacktown TS | Holroyd ZS | 5.39 | 120,430 | 156,000 | 276,430 | Close ring to simplify BU protection of Feeder 432 |
| 474 + OOS + 477 | Holroyd ZS | Westmead ZS | 5.80 | 134,600 | 223,900 | 358,500 | Close ring to Westmead ZS for protection of fdrs 477, 474, 477, 466 and 478 |
| 496 + 488 | Werrington ZS | Plumpton ZS | 4.79 | 130,030 | 291,800 | 421,830 | OF to Plumpton ZS for protection of fdrs 496 and 488 |
| 487 part | Plumpton ZS | Whalan ZS | 3.57 | 60,690 | 223,900 | 284,590 | Close ring for protection of fdrs 496, 488, 487 and 495 |
| 495 + 491 | Whalan ZS | St Mary's ZS | 5.10 | 131,700 | 223,900 | 355,600 | Close ring for prot. of fdrs 496, 488, 487, 495, 491 and 490 |
| 462 | Penrith ZS | Emu Plains ZS | 3.73 | 70,610 | 223,900 | 294,510 | OF to Emu Plains ZS for protection of fdrs 462 and 454 |
| 454 pt + 459 pt | Emu Plains ZS | Cranebrook ZS | 6.43 | 163,310 | 223,900 | 387,210 | Close ring for protection of fdrs 462, 454 and 459 |
| 451 | Cranebrook ZS | Penrith ZS | 2.73 | 50,910 | 156,000 | 206,910 | OF to Cranebrook ZS for protection of fdr 459 |
| 457 | Penrith ZS | Kingswood ZS | 3.59 | 101,530 | 223,900 | 325,430 | OF to Kingswood ZS for protection of fdrs 457 and 461 |
| 464 | Kingswood ZS | Glenmore Pk ZS | 6.00 | 102,000 | 223,900 | 325,900 | OF to Glenmore Park ZS for protection of fdr 464 |
| 231 | Glenmore Pk ZS | Regentville BSP | 1.91 | 57,670 | 223,900 | 281,570 | Close ring to Glenmore Park for protection of fdrs, 457, 461, |

| Optical fibre route | Locations | | Route length (km) | Cost estimates ($) | | | Principal purpose of the optical fibre link |
|---|---|---|---|---|---|---|---|
| | From | To | | Fibre | Term. | Totals | |
| | | | | | | | 464, 232, 231 |
| 458 part | Complete Hawkesbury TS | Cattai ZS link | 3.50 | 59,500 | 156,000 | 215,500 | Close ring to Cattai ZS for protection of fdrs 443 and 458 |
| 814 | New backbone UPC fibre | Rydalmere ZS | 0.50 | 8,500 | 223,900 | 232,400 | OF to Rydalmere ZS for protection of fdrs 814 and 816 |
| U/G | From new Guildford TS - West Parra ZS fibre | Lennox ZS | 1.00 | 107,000 | 223,900 | 330,900 | OF to Lennox ZS for protection of fdrs 417 and 418 |
| LV | Granville ZS | Sherwood ZS | 4.30 | 91,100 | 223,900 | 315,000 | OF to Granville ZS to provide alternative protection to copper pilots on feeders 9J8 and 93J/2B |
| 744 | Horsley Park ZS | West Wetherill Park TS | 4.09 | 200,030 | 223,900 | 423,930 | OF to Horsley park for protection of fdr 744 |
| 469 + | Jasper Rd ZS | West Castle Hill ZS | 3.94 | 205,580 | 223,900 | 429,480 | Close ring for protection of fdrs 469 and 484 |
| 444 + | Riverstone ZS | Vineyard BSP | 4.02 | 68,340 | 223,900 | 292,240 | OF to Riverstone ZS for protection of fdrs 441, 444 and 458 |
| 524 | Preston ZS | West Liverpool TS | 3.03 | 324,210 | 223,900 | 548,110 | Close ring for protection of fdrs 505, 524 and new feeders to Edmondson Park ZS |
| 441 | Quakers Hill ZS | Riverstone ZS | 9.24 | 157,080 | 156,000 | 313,080 | Close ring for protection of fdrs 441, 444 and 458 |
| 464 | Luddenham ZS | Glenmore Park ZS | 8.03 | 136,510 | 223,900 | 360,410 | OF to Luddenham ZS for protection of Feeder 464 |
| 512 | Kemps Creek ZS | Hinchinbrook ZS | 9.30 | 158,100 | 223,900 | 382,000 | OF to Kemps Creek ZS for protection of Feeder 512 |
| Tee off fdr 457 | 457 to Kingswood ZS | Claremont Meadows ZS | 4.50 | 99,000 | 145,900 | 244,900 | OF to Claremont Meadows ZS for prot. fdrs 457 and 485 |
| 516 part | Moorebank ZS | New Chipping Norton ZS | 3.20 | 63,400 | 145,900 | 209,300 | OF to Chipping Norton for prot of fdrs 516 and 501 (ex 504) |
| **Sub totals ($M)** | | | **158km** | **4.04** | **7.94** | **11.99** | |
| Additional 10% length/install for loops ($M) | | | | | | 0.40 | |
| Project development and management costs ($M) | | | | | | 1.69 | |
| **Total ($M)** | | | | | | **14.08** | |
| Contingency (15%) | | | | | | 2.11 | |
| **Grand Total ($M)** | | | | | | **16.19** | |

**Table 7 – ADSS optical fibre network indicative cost components**

| ITEM | COST | COMMENT |
|---|---|---|
| **Per km** | | |
| Fibre design | $3,500 | |
| Fibre construct | $10,000 | |
| Fibre supply | $3,500 | |
| **Subtotal overhead construction** | **$17,000** | **per km** |
| Fibre design | $3,500 | |
| Fibre underground | $100,000 | |
| Fibre supply | $3,500 | |
| **Subtotal underground construction** | **$107,000** | **per km** |
| | | |
| **Per substation (initial installation)** | | |
| Site civils | $47,000 | |
| MPLS construct | $10,000 | |
| MPLS install | $2,000 | |
| Batteries | $4,500 | |
| Rectifiers | $4,400 | |
| **Subtotal per site** | **$67,900** | |
| | | |
| **Per fibre termination** | | |
| Fibre design | $5,000 | per fibre termination |
| Inside sites | $43,000 | per fibre per substation |
| Protection panel and relays | $30,000 | per feeder per substation site |
| **Subtotal per fibre per site** | **$78,000** | |
| | | |
| **Per project** | | |
| MPLS design | $400,000 | per project (of this size) |
| **MPLS NMS license** | $250,000 | per project (of this size) |
| Project management | $750,000 | assume 3 FTE/year |
| Internal resources | $150,000 | assume 1 FTE/Year |
| Ancillary equipment | $140,000 | |
| **Subtotal per project** | **$1,690,000** | |

A diagram of the complete optical fibre network including optical fibre already installed or approved for installation and proposed OPGW, ADSS and underground fibre works for the Western Sydney area, is shown in Figure 2 below. Refer Appendix A for a larger copy of the plan.

### 4.3 HARDEX replacement with OPGW vs aluminium earthwire

Consideration was given to the question of replacement of the earthing and shield wire functions of the HARDEX with an aluminium earthwire compared to the use of OPGW for that purpose.

There currently is a cost premium in the order of 10% for the supply and installation (using internal resources) of 18.1mm OPGW compared to the electrically equivalent 19/3.25AAC earthwire.

The stakeholder team considered that this differential was not sufficient to warrant the installation of earthwire rather than OPGW.

**Figure 2 – Optical fibre roll-out plan for Western Sydney**

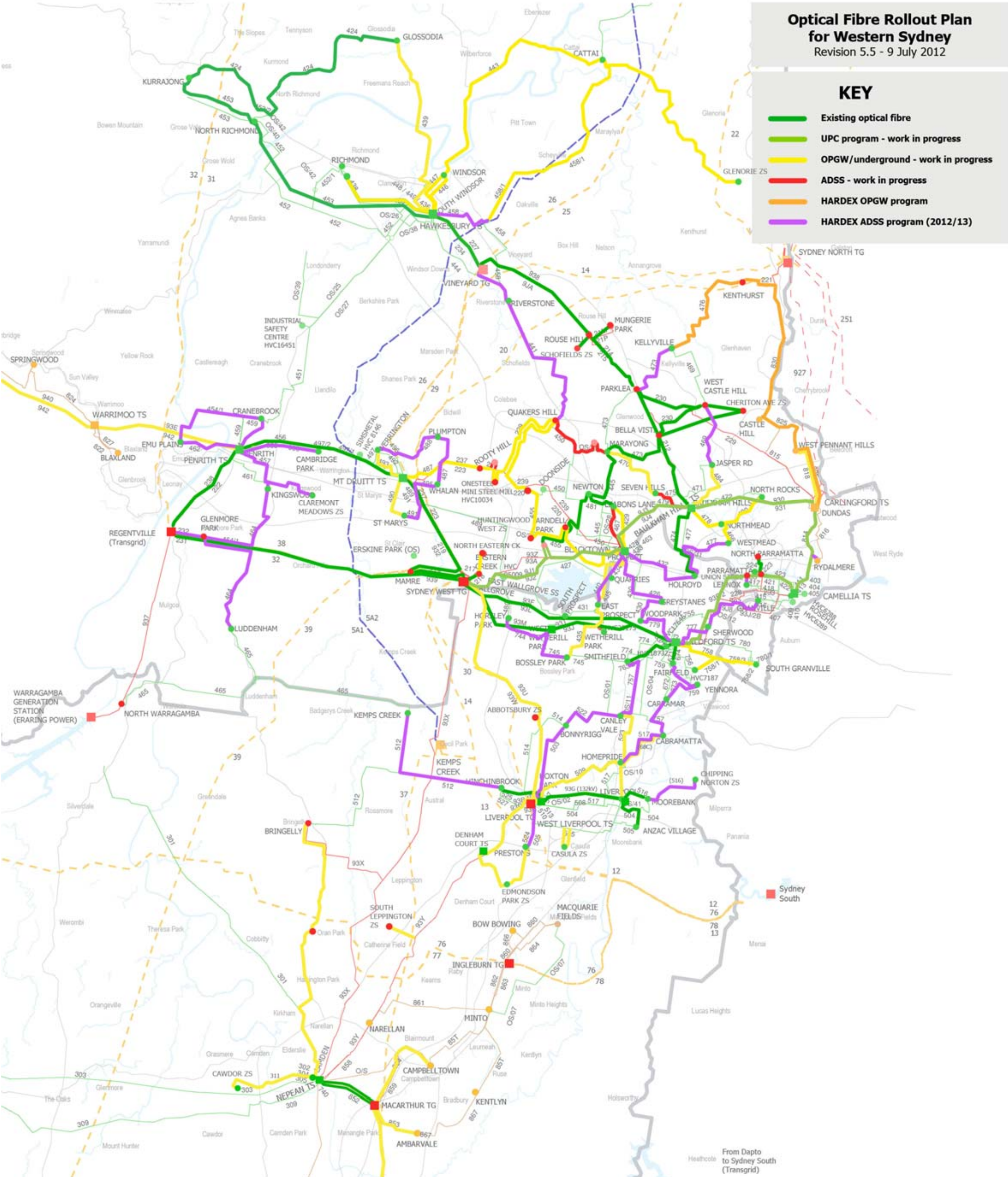


**Figure 2 notes**

- "Existing optical fibre" includes OPGW, ADSS and underground optical fibres already in service and the TransGrid link from Regentville to Sydney West TG;
- "UPC program – work in progress" includes the OPGW and underground fibre ring which is being built for the 132kV network (under program TM01301) from Sydney West TransGrid to Carlingford TS and back through Camellia TS, Parramatta and Guildford TS;
- "OPGW/underground – work in progress" includes OPGW and or underground optical fibre on new and augmented feeders and cables and Hardex replacement projects which are approved but not yet complete and in service;
- ADSS – work in progress" includes the existing approved ADSS projects under the SmartGrid program;
- "HARDEX ADSS program" includes the works in the current program for replacing the HARDEX communications functions and closing the optical fibre rings with ADSS.

Whilst ADSS is considered to provide an adequate optical fibre system and thus the strategy of widespread deployment of ADSS is proposed in this business case, there is also no question that OPGW is a more robust system with longer life and reduced susceptibility to damage from the elements, from birds and from machinery over its life. Thus it is considered that installing OPGW will provide the opportunity for ADSS links within the network to be replaced with OPGW at minimal cost should any problems arise with the ADSS in the future.

Thus it is proposed that where HARDEX is replaced, that it be replaced generally with OPGW. The earthing functions of the OPGW should be completed but at joints and terminations the OPGW should be coiled up and the fibres sealed and left secured ready for splicing and termination when required in the future.

In some situations, such as on long semi-rural feeders, a small earthwire may only be required and considerable savings may be achieved (by avoiding pole replacements etc) by installing just the earthwire, rather than OPGW. These situations should be considered on a case by case basis during the development of the ongoing program for the SARP each year or during development of the business case for the works.

### 4.4 Alternative approaches

An alternative approach to the proposed strategy is to accelerate the program of roll-out of OPGW. This would be the ideal situation which would achieve the twin objectives of rapid deployment of an optical fibre network to meet the network protection and data communication needs and provision for the renewal of the earthing functions of the HARDEX.

However, Endeavour Energy does not have sufficient internal resources to undertake this work and thus it would have to be undertaken by external service providers.

As noted above, tests of the market to date are that the installation of OPGW using external service providers will cost $50,000 - $100,000 per kilometre more than with internal resources. This cost differential is well in excess of the cost of the installation of ADSS which is less than $25,000 per km.

Thus, whilst the proposed strategy does include a "doubling up" of the roll-out of optical fibre with a rapid deployment of ADSS in the short-term followed by the replacement of HARDEX with OPGW (in the Northern and Central regions at least) in the longer-term, it still represents the most cost-effective pathway to achieving the strategic communications and renewal objectives of the organisation within a viable timeframe.

## 5.0 PROPOSED WORKS

There are three elements to the works proposed in this business case:

- The replacement of HARDEX with OPGW on a number of 66kV and 33kV feeders in the 2013/14 and 2014/15 years (Table 8 below);
- Additional funding for the works to replace HARDEX with OPGW previously approved in 2009 (Table 9 below);
- The installation of ADSS optical fibre communications links and protection relays to complete the replacement of the HARDEX protection communications functions in Western Sydney, in the 2012/13 year (Refer 5 above).

**Table 8 – New HARDEX replacement with OPGW in this business case**

| Fdr No. | From | To | Cost estimates ($,000) | | Comments |
|---|---|---|---|---|---|
| | | | 13/14 | 14/15 | |
| 825 | Carlingford TS | Castle Hill Tee West Pennant Hills | 950 | | Install OPGW including terminations and protection relays at each substation. |
| 774 | Guildford TS | Smithfield ZS | | 520 | Install OPGW as an earthwire |
| 777 | Guildford TS | Sherwood ZS | | 300 | “ |
| 779 | Guildford TS | Woodpark ZS | | 450 | “ |
| 454 | Penrith TS | Emu Plains ZS | | 670 | “ |
| 456 | Penrith TS | Cambridge Park ZS | | 630 | “ |
| 459 | Penrith TS | Cranebrook ZS | | 660 | |
| 457 | Penrith TS | Kingswood ZS | | 480 | “ |
| 471 | Baulkham Hills TS | Jasper Road ZS | | 490 | “ |
| 472 | Baulkham Hills TS | North Rocks ZS | | 550 | “ |
| 475 | Baulkham Hills TS | Seven Hills ZS | | 360 | “ |
| **Annual totals ($M)** | | | **0.95** | **5.11** | |
| **Project total** | | | | **6.06** | |
| **Contingency ($M)** | | | | **0.91** | 15% |
| **Grand total for new OPGW works ($M)** | | | | **6.97** | |

**Table 9 – Completion of the HARDEX replacement with OPGW previously approved**

| Fdr No. | From | To | Cost estimates ($,000) | | | Comments |
|---|---|---|---|---|---|---|
| | | | 12/13 | 13/14 | 14/15 | |
| 439 | Hawkesbury TS | Glossodia ZS | 1,620 | | | Install OPGW including terminations and protection relays at each substation. Originally approved in May 2009. Additional funding required for 2012/13 year |
| 446 | Hawkesbury TS | Windsor ZS | 465 | | | |
| 447 | Hawkesbury TS | Windsor ZS | 465 | | | |
| 509 | West Liverpool TS | Homepride ZS | 140 | | | |
| 470 | Seven Hills ZS | Marayong ZS | | 740 | | |
| 484 | Baulkham Hills TS | Jasper Rd ZS | | 820 | | |
| 493 | Mount Druitt TS | Werrington ZS | | 310 | | |
| 818 | Carlingford TS | West Pennant Hills ZS | | 630 | | |
| 435 | Blacktown TS | Bossley Park ZS | | | 1,800 | |
| **Annual totals ($M)** | | | **2.69** | **2.50** | **1.80** | |
| **Project total ($M)** | | | | | **6.99** | |
| **Contingency ($M)** | | | | | **1.05** | 15% |
| **Approved funding remaining ($M)** | | | | | **2.25** | |
| **Grand total for previously approved works ($M)** | | | | | **5.79** | (including contingency) |

Thus the works proposed include:

### 5.1 Optical fibre works:

- Installation of OPGW on the overhead sections of Feeder 825. Total overhead length approximately 5.7km;
- Installation of optical fibre cable with the underground sections of Feeder 825. Total underground length approximately 2.9km;
- Installation of optical fibre marshalling racks and MPLS routers at Carlingford TS and West Pennant Hills ZS;
- Termination of the optical fibre cables into the marshalling racks at each of the substation control buildings
- Commissioning of the MPLS onto the network and integration and transitioning of existing communications links and services;
- Installation of optical fibre relays at each substation and commissioning of unit protection schemes on Feeder 825;
- Decommissioning and disposal of the existing Hardex pilot wires and existing protection schemes once the optical fibre network is operational. The existing relays may be retained for spares or disposed of as required.

### 5.2 Earthwire works:

- Replacement of the HARDEX with OPGW on 33kV feeders 774, 777, 779, 454, 456, 459, 457, 471, 472, 475 including assessment of prevailing fault levels and earthwire rating;
- Bonding of the new earthwire to the substation earthgrid at each end of each feeder;
- Provision of continuity of the earthwires through each underground cable section.

Note that the OPGW will initially perform only as an earthwire but should be installed so that it can be terminated in each substation and used as an optical fibre link when required in the future.

### 5.3 ADSS optical fibre works:

- Design of the routes between the substations listed in Table 5 nominally on the feeders listed or alternative routes if required;
- Installation of ADSS on the overhead sections of the feeders and or LV circuits. Total overhead length approximately 157km (including 10% for loops);
- Installation of optical fibre cable with the underground sections of the feeders or routes. Total underground length approximately 16km (including 10% for loops);
- Installation of optical fibre marshalling racks and MPLS routers at each of the substations connected;
- Termination of the optical fibre cables into the marshalling racks at each of the substation control buildings;
- Commissioning of the MPLS onto the network and integration and transitioning of existing communications links and services;

- Installation of optical fibre relays at each substation and commissioning of unit protection schemes on the feeder affected;
- Decommissioning and disposal of the existing protection schemes once the optical fibre network is operational. The existing relays may be retained for spares or disposed of as required.

### 5.4 Review of environmental factors

A Review of Environmental Factors (REF) is required to be carried out for each feeder or group of associated feeders or optical fibre installation as appropriate. Particular attention should be paid to pole replacement works and replacement of ducts where required.

Accordingly, sufficient time and funding should be allowed for the impact assessment and the associated community consultation works and for the determination of the REF.

## 6.0 DEVELOPMENT TIMEFRAME AND STAGING

Table 10 below shows the proposed timing of each of the elements of this business case. The remaining stages of the ADSS program and the longer term HARDEX replacement works are noted in Table 10 but will be addressed by future business case(s) after further assessment of the asset needs in those areas.

**Table 10 – Proposed works schedule**

| | Works | 12/13 | 13/14 | 14/15 | 15/16 – 21/22 |
|---|---|---|---|---|---|
| **This business case** | Completion of previously approved works replacing HARDEX with OPGW | 509, 439, 446, 447 | 818, 493, 484, 470 | 435 | |
| | HARDEX and protection relay replacement + OPGW link installation on Feeder 825 | | 825 | | |
| | HARDEX earthwire replacement (with OPGW) on the first set of 33kV feeders | | | 774, 777, 779, 454, 456, 457, 459, 471, 472, 475 | |
| | ADSS and UG fibre rollout to complete fibre rings to provide for HARDEX protection pilot + relay replacement | Western Sydney | | | |
| **Future business case(s)** | ADSS and UG fibre rollout to complete fibre rings to provide for HARDEX and copper pilot protection pilot wire + relay replacements | | Macarthur & Blue Mountains | Wollongong – Port Kembla | |
| | HARDEX earthwire replacement (with OPGW or aluminium earthwire) on the remainder of the feeders currently fitted with HARDEX | | | | 48 feeders |

# 7.0 PROJECT COSTS AND FUNDING

## 7.1 Project Cost Estimates

The proposed works are in three parts as noted above.

***1) New HARDEX replacement with OPGW (Table 8).***

The total expenditure is estimated to be $6.06 million including the termination of the optical fibre and associated protection works as required.

A contingency amount of approximately 15% is proposed to cover unforeseen requirements which may be discovered as the optical fibre is rolled out. Such situations may include the need to replace additional poles in the overhead section of the lines and to provide new ducts for the underground sections.

The contingency amount totals $0.91 million and thus the cost estimate, for this part of the project, including contingency, totals $6.97 million.

***2) Completion of HARDEX replacement works previously approved (Table 9)***

This part of the project seeks additional funding to complete the works which were originally approved in 2009. The additional funding is needed to cover the increase in the cost of the installation of OPGW and underground optical fibre which has become apparent since the original Hardex replacement plan and business case was approved in 2009. Refer Appendix B for the IGC approval memo of May 2009.

Much of the cost increase has come about due to increased restrictions on closures of roads and requirements for traffic control and the hours in which work on or near roads can be carried out.

The scope of the projects has also increased since 2009 and now includes optical fibre marshalling panels and protection relays, which were previously left for the protection refurbishment program PS008, to address.

CPI increases from 2009 have also been factored into this amount.

Thus the revised cost of the works previously approved is expected to total $6.99 million compared to the original estimate of $4.81 million.

A contingency of $1.05 million or 15% of the cost of the outstanding works is proposed to cover unforseen events and in particular, the replacement of additional poles in the overhead sections and ducts in the underground sections of the lines and modifications to the control buildings to accommodate the optical fibre termination equipment.

$2.25 million of the original approved funding remains remains unspent to date as carry-over and thus the additional funding required totals $4.74 million, plus the contingency of $1.05 milion, which brings the total to $5.79 million.

***3) ADSS and underground optical fibre network roll-out (Table 5)***

The total cost of the works proposed to complete the optical fibre network in Western Sydney as detailed in tables 5, 6 and 7 is $14.08 million.

A contingency of $2.11 million or 15% of the cost of the works is proposed to cover unforseen events and in particular, the replacement of additional poles in the overhead sections and ducts in the underground sections of the lines and modifications to the control buildings to accommodate the optical fibre termination equipment.

Thus the total cost estimate, including contingency, for this part of the project, is $16.19 million.

Table 11 below shows a breakdown of the proposed funding requirements.

### 7.2 Funding provisions

As shown in Table 12, the SARP 2012/13 and SAMP 2011 contain sufficient funding allocations for the works proposed.

Further funding will be required in 2014/15 and this will be addressed in the next revision of the SARP in conjunction with the development of the projects to provide an optical fibre network in the Blue Mountains and Macarthur areas and the Wollongong and Port Kembla areas. Further business cases will be prepared to describe these works and the network renewal needs that they will address.

**Table 11 – Proposed expenditure and funding requirements**

| Item | Proposed expenditure ($M) | | | | Comments |
|---|---|---|---|---|---|
| | 12/13 | 13/14 | 14/15 | Sub-totals | |
| **1a.** HARDEX - OPGW fibre link installation | | 0.95 | | **0.95** | Feeder 825 |
| **1b.** Hardex earthwire replacement with OPGW | | | 5.11 | **5.11** | Feeders 774, 777, 779, 454, 456, 457, 459, 471, 472 and 475 |
| **2.** HARDEX - OPGW replacement works previously approved | 2.69 | 2.50 | 1.80 | **6.99** | Works previously approved in 2009 and 2011 (refer Table 3). These works require additional funding in 2012/13. |
| Contingency amount | 0.40 | 0.52 | 1.04 | **1.96** | 15% |
| **OPGW Subtotal ($M)** | **3.09** | **3.97** | **7.95** | **15.01** | |
| Less previous approved funding remaining | 2.25 | | | **2.25** | |
| **OPGW total ($M)** | **0.84** | **3.97** | **7.95** | **12.76** | |
| **3.** ADSS installation | 14.08 | | | **14.08** | ADSS and underground optical fibre links, terminations and protection relays in Western Sydney as per Table 5 |
| Contingency amount | 2.11 | | | **2.11** | 15% |
| **ADSS Subtotal ($M)** | **16.19** | | | **16.19** | |
| **Total ($M)** | **17.03** | **3.97** | **7.95** | **28.95** | |
| **Grand total this business case ($M)** | | | | **28.95** | |

Table 12 below shows the programs within the SARP 2012/13 which include funding allocations for the proposed works.

**Table 12 – Funding Table**

| Item | 12/13 | 13/14 | 14/15 | Comments |
|---|---|---|---|---|
| **Total estimated expenditure** | **17.03** | **3.97** | **7.95** | **Funding approval required for this business case** |
| **SARP/SAMP provisions** | | | | |
| Program TM01303 | 5.10 | 1.47 | 3.33 | HARDEX replacement |
| Program TM01302 | 0.00 | 1.70 | 1.80 | Copper pilot wire replacement – principally in the Wollongong and Port Kembla areas |
| Program SG001 (SAMP 2011) | 17.29 | 19.48 | | ADSS optical fibre network and communications roll-out |
| Program PS008 | 0.67 | 0.70 | 0.70 | Protection relay replacement. Only part which corresponds with the relevant sites has been included |
| **Total funding provision** | **23.06** | **23.35** | **5.83** | **Total funding available** |
| **Net balance of funding ($M)** | **6.03** | **19.3** | **-2.12** | Balance of existing funding allocations and funding required (+ = excess funding, - = additional funding req'd). |

Overall, the funding balance is positive and it is proposed that the excess funding from 2012/13 and 2013/14 will be carried over in to the 2014/15 year.

## 8.0 RECOMMENDATIONS

It is recommended that the HARDEX pilot cable replacement strategy as described in this business case, be endorsed. The strategy includes the replacement of the pilot wire functions of the HARDEX with an optical fibre network utilising ADSS, OPGW and underground optical fibre in the short-term, followed by the replacement of the earthwire functions of the HARDEX with a combination of OPGW and aluminium earthwire, as appropriate to the individual situation, in the longer-term.

Accordingly, it is recommended that approval be given for:

- A capital expenditure of $6.06 million for the installation of OPGW optical fibre links on the 66kV Feeder 825 and associated optical fibre termination and protection works and for the replacement of the HARDEX earthwires on 33kV feeders 774, 777, 779, 454, 456, 457, 459, 471, 472 and 475.
- A contingency sum of $0.91 million to cover unforeseen events, in particular the replacement of additional poles in the overhead sections and ducts in the underground sections of the above lines.
- An additional amount of funding for $4.74 million to complete the works of replacing HARDEX earthwire and pilot with OPGW approved in 2009;
- A contingency sum of $1.05 million to cover unforeseen events associated with the works previously approved, in particular the replacement of additional poles in the overhead sections and ducts in the underground sections of the lines;
- A capital expenditure of $14.08 million for the installation of ADSS and underground optical fibre links and associated optical fibre termination and protection works to complete the replacement of the communication pilot functions of the HARDEX in Western Sydney;
- A contingency sum of $2.11 million to cover unforeseen events, in particular the replacement of additional poles in the overhead sections and ducts in the underground sections of the lines and modifications to the control buildings to accommodate the optical fibre termination and replacement protection equipment.

Accordingly, the estimate of the cost for the works, for which approval is sought, including the contingency amounts, totals $28.95 million.

## 9.0 APPENDICES

**APPENDIX A -** Schematic diagram of existing and proposed optical fibre network in Western Sydney.

**APPENDIX B -** IGC Hardex Renewal Plan endorsement memo, 22 May 2009.

**APPENDIX C -** Detail of recent HARDEX failures.

## 10.0 REFERENCES

1) Hardex Pilot Cable Renewal Project TM013-03, Renewal Plan, Revision 3.0, 27 May 2009. Strategic Asset Management Branch.

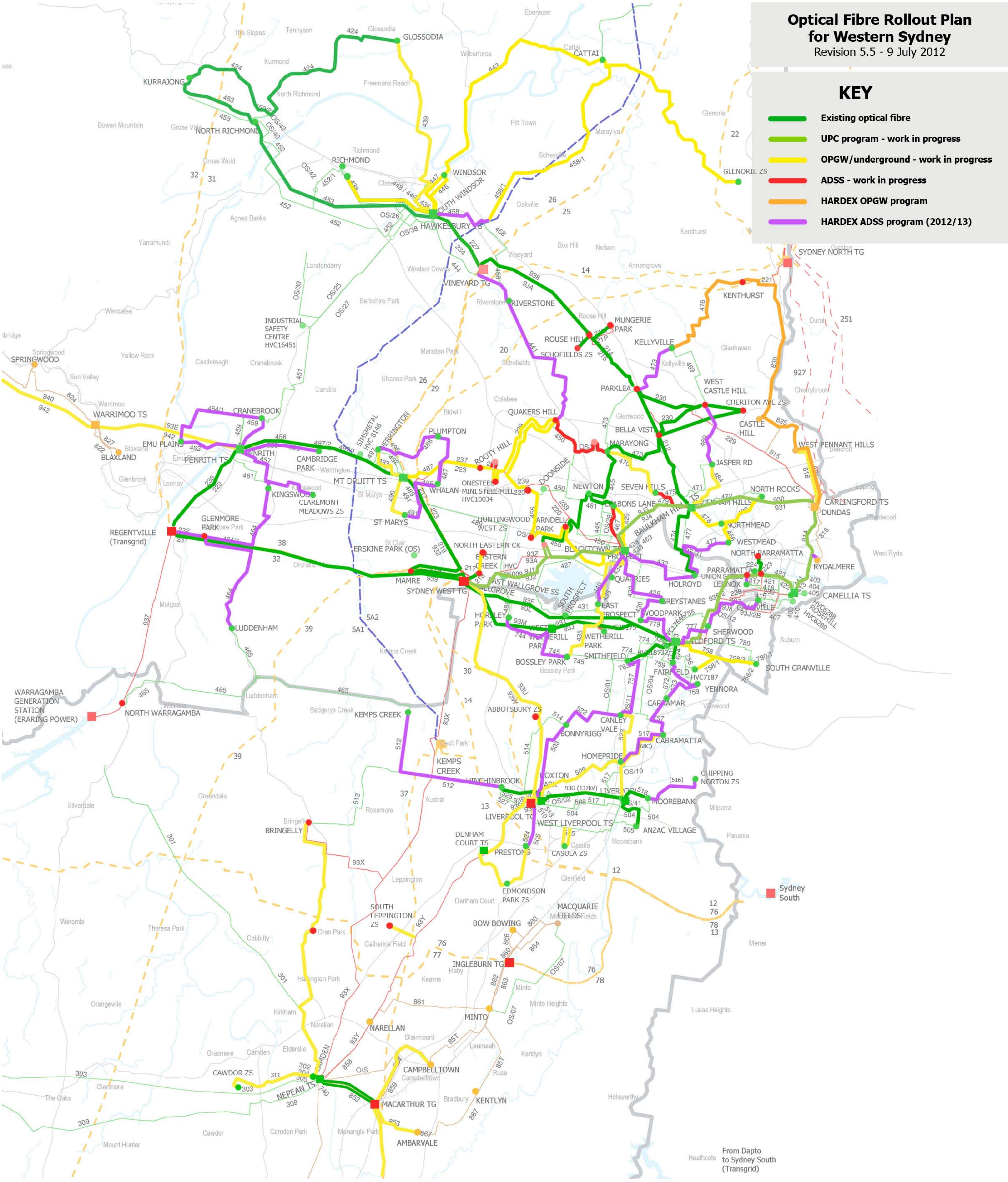
2) Project SG001 – Fibre and MPLS Communications, Business Case 2011/12. Network Technology Strategy Branch. 22 February 2012.

3) Hardex Renewal Plan (v13, 9-07-12,jc)(incl ADSS), spreadsheet. Strategic Asset Management Branch.

4) Strategic Asset Renewal Plan (SARP) 2012/13 – 2021/22. Strategic Asset Management Branch, 28 October 2011.

5) Strategic Asset Management Plan (SAMP) 2011 - 2021. Strategic Asset Management Branch, 29 September 2011.

**Schematic diagram of existing and proposed optical fibre network in Western Sydney**



## IGC Hardex Renewal Plan endorsement memo

ORIGINAL

INTEGRAL energy
The power is in your hands

**Internal Memo**

| | | |
|---|---|---|
| **To:** | Vince Graham | **File no:** **Item 08 (CGC 20/05/09)** |
| **From:** | Joseph Pizzinga | **Date:** 22/05/09 |
| **Subject:** | Capital Governance Committee (the "Committee")<br>Hardex Pilot Cable Renewal – Project Capital Expenditure | |

**Purpose**

To obtain endorsement from the Committee for the Chief Executive Officer to approve $5.1M of project capital expenditure for the TM013-03 Hardex Pilot Cable Renewal project.

**Background**

A paper requesting endorsement by the Committee for the CEO to approve $5.1M of project capital expenditure for the TM013-03 Hardex Pilot Cable Renewal project was presented by Ty Christopher and Michael Tamp. Of this total, $0.7M was requested for 2010/11, $2.6M for 2011/12, and $1.8M for 2012/13.

Hardex consists of a pilot cable surrounded by a galvanized steel earth wire. Hardex is installed on approximately 420km of selected 33kV and 66kV within the Northern and Central regions, to provide communications, protection and earthing services. These Hardex cables now average 40 years of age, and are at or approaching the end of their economic life, and require asset replacement/renewal. In addition, some Hardex cables have experienced lightning strikes, which have damaged or destroyed their communications capability.

The paper presented advocated the commencement of a program of Hardex cable replacement, with either OPGW or ADSS cables. OPGW is the current IE standard replacement for Hardex, however ADSS is widely used by communications companies, and some electricity distributors.

**The Committee requested** that a report (in late 2011, based on the work undertaken in 2010/11) be prepared recommending whether OPGW or ADSS should be adopted as the IE standard for pilot cables.

**The Committee also requested**, as an Action Item, that the costs on page 19, and the risk rating of 5 for ADSS on page 21, of the paper, be confirmed.

**The Committee endorsed** that the CEO approves the $0.7M of capital expenditure requested for 2010/11, the $2.6M requested for 2011/12, and also sufficient capital expenditure for the feeder 439 replacement component of the $1.8m requested in 2012/13.

**Recommendation**

It is recommended that the Chief Executive Officer approves the $0.7M of capital expenditure requested for 2010/11, the $2.6M requested for 2011/12, and also sufficient capital expenditure for the feeder 439 replacement component of the $1.8M requested in 2012/13.

Endorsed by:

Joseph Pizzinga
**Chief Financial Officer**
Dated: 28 . 5 . 09 .

Approved/~~Not Approved~~ by:

Vince Graham
**Chief Executive Officer**
Dated: 27/5/09

## APPENDIX C

## Detail of recent HARDEX failures

| Feeder No. | From | To | Incident/comments (System Operations) |
|---|---|---|---|
| 509 | West Liverpool TS | Homepride ZS | defective pilot wires feeder 509 33KV pilot burnt down between poles #123 & 122 @ Maxwell Ave Ashcroft see also T/O 1133542 for 11kV CB A324 trip & reclose @ Homepride Z/S. Flying fox in 33kV mains. P&C to carry out pilot checks/test & Trans Mains to replace pilot. CB 15252. Fdr - 509. West Liverpool T/S. Temporary protn installed at both West Liverpool & Homepride. Sept 08 - Mains have been reinstalled - repairs to pilots to follow. Oct 08 - Pilot repaired by Mains - now due for Protn tests next Friday 31st -if OK RTS due. Nov 08 - Mains carried out repairs but pilot failed testing. 12/12 for return of Mains to carry out further repairs. Dec 08 - Pilots have been repaired - to be tested & RTS by 31/12. Jan 09 - Pilot repaired in December - tested 31/12 but failed. Mar 09 - Faulted sections replaced with Hardex now waiting testing. July 09 - fault found at Pole 112. Sept 09 - Fault located between poles 91 & 96. Oct 09 - Main repair - 17th Oct. Test 24th Oct & final test (hopefully) 26th Nov. Nov 09 - retested and found 4 new faults. Jan 10 - Outage required but denied by Sys Ops - March |
| 435 | Blacktown TS | Bossley Park ZS | Defective Pilot Wires Fdr 435 33kV Fdr 435 lockout - 3 phase XLPE single core Raychem. Pole 40 - UGOH blown up and pilot cable fault (back entrance to Water Board) beside the T-way - off Davis Street Wetherill Park. CB 16505. Fdr - 435. Blacktown T/S. Patrolman to investigate. Nov 08 - Mains have carried out repairs & ready for testing. Jan 09 - Repairs done now requires testers. Mar 09 - Fdr to be retested and all connections remade before 30/4. July 09 - This is 6th on the list! Aug 09 - Feeder to be tested on Sept 15th hopefully any issues will be rectified. Oct 09 - Testing booked for 11/11. Jan 10 - Multiple pilot boxes & joints repaired / replaced. More faults exist & pilot will be sectionalised & tested 9/10 March. April 10 - appears to be 3 good cores end to end. Further outage required to remake some pilot boxes and test end to end. 4th June 10 - programmed for 8th & 9th June. June 10 - further fault found - hit by lightning since last test. Will require retesting etc. July 10 - 14/15 July failed again with pilot defect at poles 24/25 at UG/OH possibly from lightning strike at pole 24. |
| 470 | Seven Hills ZS | Marayong ZS | defective pilots feeder 470 Translay pilot down into 11kv mains at pole 95 for one bay Fredrick St Blacktown. Pilot wire cut away at fault site and temporary protection installed at Seven Hills. Limitations of network & at Marayong which is normally fed from Fdr 445 ex Blacktown with C/O to Fdrs 473 & 470. Jan 09 - Fdrs 473 & 470 can run in //. Mar 09 - Mains repaired awaiting HV test. June 09 - Testing to be carried out 24/7. July 09 - This is 6th on the list! Aug 09 - Further faults found which would require restringing 10 bays of Hardex. Nth Reg preparing quote for change control to replace with OPGW this financial year. Sept 09 - Further faults found requiring 10 bays of Hardex to be replaced. Nth Region to quote "change control" to replace with OPGW this financial year. Jan 10 - no recovery work carried out. No window from Sys Ops due to "Hot Days". Feb 10 - Finances become available next Financial year and when that occurs work could proceed. Aug 10 - Robert Armstrong will talk to John Broadhead 4 timing of recovery. Dates will be provided. Nov 10 - Design completed for OPGW - requires final approvals & PM to arrange for protection designs for new. |
| 480 | Baulkham Hills TS | Northmead tee Northrocks ZS | Defective pilots fdr 480 Low IR reading on Fdr 480 - Baulkham Hills Z/S. CB 15944. P&C to investigate. Oct 09 - Testing g - 7/11 the full test on 20/11. Nov 09 - Cancelled due to "hot day" - requires reprogramming. Feb 10 - System Ops provides window on 17 & 18th March to recover. Mar 10 - 26/3 more faults found will require access again. April 10 - Testing to be carried out on May 21st. July 10 - Hammers Rd cnr Centenary Rd UG/OH fault - Noel to program. Sept 10 - Fault found in underground section at intersection of hammers & centenary rd reprogram in November. Same result as July 10... Nov 10 - fault found in UG section at intersection of hammers & centenary ave. To be programmed for early Jan 11 when staff become available. Feb 11 - Noel Langby to excavate B4 end of Feb & begin repairs. McCann¿s Excavators to dig & lay conduits then install pilots etc. March 11 - Now put back until end of April.. April 11 - fault found in UG section at intersection of hammers & centenary rd unfortunately incorrect size cable had previously been installed and will require replacement. |
| 487 | Mt Druitt TS | Plumpton ZS | defective pilots Translay pilots defective due to primary fault adjacent to TS. Temporary O/C protection installed reclose at single shot. Aug 10 - Pilot reinstated but all cores open circuited. Sept 10 - Programmed 4 19th Oct but cancelled Jan 11 - New Fault found 28/2 new test/repair date Feb 11 - June B4 repairs done. April 11 - Pilot burnt down during feeder fault and has been reinstated however all cores still test open circuit. After testing, found from tee pole to Whalan is free of faults but unable to test towards Plumpton as last span to tee pole is damaged and needs to be repaired. Also faults towards Mt Druitt but unable to patrol this section due to boggy ground - mains to repair in May. May 11 - no update at hand. Aug 23 - status quo Oct 2011 - waiting new procedure GNV1066 once Ken Collins has repaired span Nov 2011 - status quo Dec 2011- awaiting test pilot procedure trial Feb 2012 - status quo March 2012 - possible sometime this month April 2012 - repairs attempted 7/8 March rained out whalan section ok section to mt druitt suspect |
| 755 | Guildford TS | Sherwood ZS | defective pilots feeder 755 guildford Defective pilot ,FDR 755 Intertrip fault alarm P& C has put temp distance prot Aug 23 - fault found, repairs test september ?? Oct 2011 - status quo Nov 2011 - status quo Dec 2011- status quo Feb 2012 - Ken Collins to schedule early 2012??? March 2012 - status quo April 2012 - status quo possible may 2012 |
| 456 | Penrith TS | Cambridge Park ZS | pilot wires down feeder 456 Trip Fdr 456.AT Pole 701 bays of HARDEX Pilot wire down. Oct 2011 - status quo Nov 2011 - status quo Dec 2011- status quo Feb 2012 - status quo March 2012 - status quo April 2012 - with huntingwood for further advise on what to do see defect T371 33 switchgear cambridge pk zone |
| 825 | Carlingford TS | West Pennant | Defective pilots fdr 825 Trip FDR 825, Several bays of 66KV Mains down, 2 bays of pilots down pilot to be |

| Feeder No. | From | To | Incident/comments (System Operations) |
|---|---|---|---|
| | | Hills tee Castle Hill ZS | replaced back to T/S at Carlingford. Temp protection Installed Dec 2011- stringing new pilots sunday 18th Feb 2012 - testing to occur in feb/march March 2012 - Possible this month April 2012 - failed test march 8 WPH to carlo failing |
| 454 | Penrith TS | Emu Plains ZS | Defective Pilot wires Fdr 454 Loss of Emu Plains ZS (lockout Fdrs 462 & 454 at Penrith) 4 bays pilot down Fdr 454 Castlereagh Rd cnr Andrews Rd - Pilots to be repaired. Possible cause previous lightning strike. April 2012 - status quo |
| 516 | Liverpool TS | Moorebank ZS | Pilot Wire Failure Feeder 516 Pilot Wire Failure Feeder 516 Liverpool TS Pilot wire box corner ridge and moorebank av damaged by birds structure 16 temp protection installed liverpool |