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SA Power Networks: Installation of Rapid Earth Fault Current Limiting (REFCL)/Ground Fault Neutralising (GFN) Technology Business Case

October 2014

Installation of Rapid Earth Fault Current Limiting (REFCL) / Ground Fault Neutralising (GFN) Technology

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1. Document Authorisation and History

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25/9/2014	0.2	Elisia Reed	Changes based on David Pritchard's comments.
10/10/14	0.3	Elisia Reed	Updated references.

2. Executive Summary

Several bushfire risk mitigation strategies have been proposed by SA Power Networks for implementation in the 2015 - 2020 regulatory period. Installation of Ground Fault Neutralising (GFN) / Rapid Earth Fault Current Limiting (REFCL) technology is one such strategy which has the potential to reduce the incidence of fire starts by high speed detection of earth faults in three phase power systems, with rapid reduction of earth fault current magnitudes. This strategy targets the direct reduction in likelihood of fire starts and provides safety improvements.

GFN installations at Stirling East and Uraidla substations are recommended to determine the benefits, limitations, efficiency and effectiveness of REFCL technology in reducing the number of fire starts, caused by SA Power Network assets, and to identify the operational and reliability issues that may be specific to SA Power Networks.

This business case will address some of the key issues associated with the implementation of GFN technology, the options considered and the rationale for the preferred solution. SA Power Networks believes utilising GFN technology is a cost effective way of achieving the bushfire risk mitigation objectives.

The PBST (Powerline Bushfire Safety Taskforce) estimates that REFCL technology may achieve a reduction in bushfire risk of approximately 70%.[1] REFCL technology is a cost effective bushfire risk mitigation solution and generally has a lower cost (per km comparison) than undergrounding or covered conductors.

An allowance of $12M has been requested to implement GFN technology at both Stirling East and Uraidla substations. The project is forecast to be fully implemented within the 2015 to 2020 regulatory period.

[1] Powerline Bushfire Safety Taskforce, *Final Report*, September 2011, pg.48.

3. Introduction

3.1 Purpose

SA Power Networks proposes installing Ground Fault Neutralising (GFN) / Rapid Earth Fault Current Limiting (REFCL) technology at two sites

- to gain experience with REFCL technology;
- to obtain more information about the GFN performance and effectiveness in high bushfire risk areas on SAPN's unique Distribution Network;
- to quantify the efficiency for fire start reduction;
- to enable SA Power Networks' to gain operational experience;
- to assess the compatibility/suitability of the GFN for SA Power Networks infrastructure; and
- to assess the extent of network conversion required.

SA Power Networks is committed to practically managing the risk of fire start caused by assets failing or vegetation making contact with assets and igniting a fire. The 11kV and 7.6kV assets are associated with over 50% of SA Power Networks fire starts from 2008 to 2012[2]. The PBST (Powerline Bushfire Safety Taskforce) estimates that REFCLs such as the GFN may achieve a reduction in bushfire risk of approximately 70%.[3]

REFCL technology being used for bushfire risk mitigation purposes is still in early development however trial installations by other DNSPs (Distribution Network Service Providers) in Victoria have highlighted the benefits and effectiveness of this technology (refer to reference [4] *REFCL Trial: Ignition Tests* report released August 2014 for more details). This investment is aligned with recent industry developments and trends in setting new standards in bushfire risk mitigation from electricity distribution assets.

SA Power Networks considers a cautionary approach is warranted. The significant potential of the technology deserves consideration and as such installations at two substations, in high bush fire risk areas (HBRA), to test the suitability of the technology for the SAPN network prior to selective roll-out is recommended.

There are unique differences between the Victorian distribution network trial site and the South Australian network. For example, 11kV distribution line voltages with steel "stobie" poles (which can conduct) opposed to 22kV distribution line voltages using wooden poles in Victoria. The number of distribution feeders out of a substation and the lengths of these feeders also differ. These variations may affect the efficiency and performance of the GFN for fire start reduction. There are also unique problems faced by SA Power Networks which will need to be addressed as part of the proposed installations.

For example, residual currents of the 11kV feeders must be provided to the GFN to enable fault location ability. The residual currents cannot be provided from existing protection CT's (which is possible in Victoria) as the overall ratio is greater than 400. This is a consequence of South Australia having relatively high 11kV feeder loads and using CT's with a 1A secondary.

[2] SAPN, *South Australia Power Networks Regulatory Proposal 2015–20 Attachment 20.50: Bushfire mitigation summary*, 2014, pg.6.
[3] Powerline Bushfire Safety Taskforce, *Final Report*, September 2011, pg.48.

Each GFN installation will require additional 11kV feeder CT's and the type, means and difficulty for installing these will differ depending on the existing site equipment and space limitations.

Space restrictions within the Control room and in the yard for the GFN equipment is also a concern for SA Power Networks and in some cases a substation upgrade will need to be undertaken before or as part of the GFN installation.

The proposed installation sites will allow SA Power Networks to provide hard data for fire start reduction purposes, without jeopardising public or employee safety, and to assess the installation and operational changes that would be required for roll-out in SA.

3.2 Exclusions

As GFN technology imposes a fundamental change in protection philosophy and the way SA Power Networks manages and operate the network. There are costs associated with this change which are not captured in this business case.

Excluded from this proposal are the developmental costs including documentation, training of personnel, developing fault finding techniques and operational changes that come with introducing a new technology to the organisation. Operating procedures need to be developed to address live line work and switching.

4. Background

Jacobs (formerly Sinclair Knight Merz) was engaged by SA Power Networks in August 2012 to review SA Power Networks' bushfire risk management practices and assist with the development of strategic options for bushfire risk management.

In April 2013 Jacobs was further engaged to undertake a detailed assessment of SA Power Networks' fire start history to establish root causes, and then in light of interstate and overseas experiences, assess each of the potential risk mitigation strategies, considering benefits, limitations and their effectiveness in reducing the number of fire starts.

In February 2014 Jacobs was requested to recommend a practical, cost-effective package of risk mitigation strategies necessary for SA Power Networks to comply with acceptable industry practice, to target the issues and areas of highest fire start risk, accommodate SA Power Network's capability to execute, and provide optimum fire risk mitigation benefits at a modest cost.

Undertaking installations of Ground Fault Neutralising (GFN) / Reduced Earth Fault Current Limiting (REFCL) technology in two substations, supplying high bushfire risk areas, was identified as a potential risk mitigation strategy.

5. Rapid Earth Fault Current Limiting (REFCL) Technology

Rapid Earth Fault Current Limiting (REFCL) technology has the potential to reduce the incidence of fire starts by high speed detection of single phase to earth faults, in three phase power systems, providing rapid reduction of earth fault currents.

Reducing the magnitude of single phase to earth fault currents and providing fast fault clearing times, reduces the energy into a fault. The reduced voltage and current at the fault site lowers the possibility of arcing and heat energy which reduces the potential for ignition of combustible material at the fault site.

Earth faults can occur when the phase conductor is connected to earth via a range of events including contact with vegetation, animals and insulation failure. According to new research on bushfire ignition from rural powerlines, vegetation contact and conductor failure account for 80% of fires caused by powerlines due to the poles and wires and only 20% due to the auxiliary equipment mounted on poles (e.g. transformers; fuses; surge diverters)[4].

When earth faults occur, the power system becomes unbalanced and a current path to earth is initiated that can create extremely high currents typically of many hundreds or thousands of amps if the transformer neutral is solidly grounded. REFCL technology provides resonant grounding (utilising modern derivatives of the Petersen Coil) which allows the neutral voltage of a whole distribution network to move away from zero (almost instantaneously) to reduce the voltage at the fault location and significantly reduce the earth fault current[5].

This effect is known as Neutral Voltage Displacement (NVD). When an earth fault occurs, the neutral voltage increases from generally less than 1kV to 6.3kV and the voltage on the faulted phase falls to a value close to zero (say 200V – 500V depending on the fault current levels). The voltage on each of the two healthy phases increases from 6.3kV to 11kV. Since there is minimal voltage left on the faulted phase to drive current after the neutral voltage displacement takes effect, the current drawn by the earth fault is very low.

5.1 REFCL Variants

There are two types of REFCL technologies available today. These include the Arc Suppression Coil (ASC) which has no power electronic components and the Ground Fault Neutraliser (GFN) which uses a power electronic inverter, called a Residual Current Compensator (RCC) to neutralise the remaining active current.

The ASC is a tuned reactance inserted between the transformer secondary winding star point (neutral) and earth. It is dynamically tuned to the system capacitance. It resonates with the network capacitance of the two healthy phases when a third phase has an earth fault present. As such it compensates for the network capacitive leakage currents. For example, earth fault currents could be reduced to five amps or less in comparison to a solidly earthed neutral which would have earth fault currents in the hundreds or thousands of amps.

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[4] Marxsen. T, Coldham. D, Czerwinski. A, *New Research On Bushfire Ignition From Rural Powerlines*, 2012, pg.5.
[5] Marxsen. T, Coldham. D, Czerwinski. A, *New Research On Bushfire Ignition From Rural Powerlines*, 2012, pg.6.

The GFN consists of an ASC along with a power electronic inverter (RCC) which injects an equal and opposite current (to the residual fault current) into the transformer secondary neutral that re-balances the power system and provides high speed residual current reduction. The residual current compensation is achieved by injecting a voltage into the network neutral connection to move the voltage of the faulted phase close to zero.

5.2 Utilising REFCL Technology For Bushfire Risk Mitigation

As REFCL technology is relatively new to Australia, the technology necessary to allow it to be used for bushfire risk mitigation is still in its infancy and the limited products available contribute to the slow and cautious uptake of the technology. Outside of Australia, utilising REFCL technology for fire risk mitigation has not been adopted. The main driver for resonant earthing (using ASCs) has been for network reliability as continuous supply can be maintained for short periods when earth faults occur. There has not been the demand for residual current compensation and as such there has been limited development in this area.

Approximately one hundred and seventy Swedish Neutral GFNs have been installed world-wide to date in comparison to the Czech manufacturer EGE which sells around four hundred ASCs per year world wide. In Victoria, one resonant earthing installation has been in service for five years utilising the GFN product. Additional GFN installations are being planned in Victoria. Powercor and SPAusNet are also planning further tests at a proposed SPAusNet site at Kilmore South (Victoria) which will enable them to test the GFN on a real system.

Swedish Neutral, Czech company EGE and Austrian company Trench (part of Siemens) are three manufacturers offering products to the Australian market. At present only the Swedish Neutral's GFN has been considered as it provides superior residual current reduction in comparison to the other ASC product alternatives. Ignition tests from the Powerline Bushfire Safety Program (PBSP) have shown the GFN reduces the probability of bounce ignitions at high fault current levels and exhibits a reduced incidence of ground ignitions due to lower residual current in comparison to those of an ASC.[6]

SA Power Networks have elected to move to resonant earthing selectively for bushfire risk mitigation purposes in high bushfire risk areas. Each substation network will need to be assessed on its merits and in some circumstances adoption of resonant earthing will not be suitable due to site restrictions or the amount of ancillary works making the adoption cost limiting.

5.3 GFN Efficiency

It was reported in 2011 that simulation of phase-to-ground arc faults on a GFN protected network showed the GFN may reduce ignition probability to levels close to zero based on 'worst case realistic' conditions[7].

More recently, the PBSP established the REFCL trial as a limited duration research project to test the effectiveness of REFCL technology in reducing fire risk. The report outlining the results of the REFCL trial was published in August 2014. The ignition tests were carried out on a real electricity distribution network (a purpose-built facility in Frankston Victoria). These

[6] Marxsen Consulting, *REFCL Trial: Ignition Tests,* 2014, pg.27.
[7] HRL Technology (prepared for Energy Safe Victoria), *Probability of Bushfire Ignition from Electric Arc Faults, Final Report, Report No: HLC/2010/195,* December 2011, pg.4.

tests confirmed that REFCL technology can reduce the fire risk associated with bare-wire overhead powerlines. It was found that when a live high voltage conductor falls to the ground under worst case fire weather conditions, such as those experienced on Black Saturday 2009, a REFCL can reduce the conductor-soil arcing in many circumstances to levels below that required to start a fire[8].

In 2011 it was reported that,

> *"under worst case conditions, sustained ignition is 50% probable for arc durations around 60ms at 200 amps, 75ms at 50 amps and 155ms at 4.2 amps"*[9].

Similarly, other published data based on test results stated,

> *"it can be inferred that to be 95% certain that ignition is less than 10% probable in a 'worst case' network fault, fault clearance times must be very short: 33ms for a 200A fault, 45ms for a 50A fault, and 80ms for a 4.2A fault.*[10]*"*

These results demonstrate that the efficiency of the GFN at reducing the risk of fire start depends on the amount of residual current reduction and the time required to achieve this.

The time required for the GFN to reduce the residual current is variable and is dependant on the severity of the fault impedance. Low impedance faults (greater than 50 amps) allow the GFN to rapidly reduce the fault current to approximately 1-2 amps or less in around 60ms thus reducing the probability of fire start to very low levels. High impedance faults, such as when a dry tree branch touches a powerline, can result in a gradual increase in the neutral voltage (over 1s or 2s in extreme cases). Partial neutral voltage displacement (rather than the full 6.3kV) can also occur[11]. In these instances the ability of the GFN to reduce the probability of fire start can be limited.

The GFN is designed to reduce residual fault current to near zero levels within about 20s regardless of the impedance of the fault. The REFCL Trial has shown the GFN has the ability to detect very high impedance faults (those below 5 amps which cannot be detected by traditional sensitive earth fault protection) with a fault detection sensitivity of 1 to 2 amps.[12]

The level to which the residual current can be reduced and the actual voltage on the conductor at the fault location is dependant on a number of factors including the location of the fault, load current, fault resistance, harmonic levels, the performance of the instrumentation (current transformers and voltage transformers), size of the network and how well the network is balanced (the aim is to achieve equal capacitance to earth from each of the three phases).

The GFN product available today is not tolerant of network imbalance and the degree of imbalance will affect the efficiency of the GFN[13]. Standing network imbalance can be an issue for remote rural networks with very long two-wire spur lines. Discussions with the

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[8] Marxsen Consulting, *REFCL Trial: Ignition Tests,* 2014, pg.4 & pg.7.
[9] HRL Technology (prepared for Energy Safe Victoria), *Probability of Bushfire Ignition from Electric Arc Faults, Final Report, Report No: HLC/2010/195,* December 2011, pg.3.
[10] Marxsen. T, Coldham. D, Czerwinski. A, *New Research On Bushfire Ignition From Rural Powerlines*, 2012, pg.10.
[11] Marxsen Consulting, *REFCL Trial: Ignition Tests,* 2014, pg.129.
[12] Marxsen Consulting, *REFCL Trial: Ignition Tests,* 2014, pg.15
[13] Capacitive imbalance increases the residual current (which increases the risk of fire start) and increases the standing level of neutral voltage (which constrains fault detection sensitivity).

manufacturer indicate that changing to an adaptive fault detection algorithm may offer increased tolerance for standing network imbalance.[14]

Areas with high harmonics, can limit the effectiveness of the GFN. Additional expenditure may be required to reduce the harmonics in order to improve the efficiency of the GFN such that it will be an adequate bushfire risk mitigation tool.

There are several factors that influence the fault detection sensitivity. As the GFN relies on a rise in neutral voltage (above a threshold) to detect a fault, high levels of network damping[15], severe network imbalance and large network size[16] can all contribute to a decrease in the detection sensitivity. The REFCL Trial ignition test indicated that fault detection sensitivity of 2A was expected however lower values closer to 1A or 0.5A may be feasible as a temporary fire risk reduction measure on high fire risk days.[17]

The Jacobs review of SA Power Networks' fire start history identified that the average number of fires starts attributed to SA Power Networks over the five year period 2008 to 2012 is about 67 per annum across the whole network. This includes 53 per annum in HBFRAs and MBFRAs[18]. For this same period, over 50% of fires starts occurred on 11kV and 7.6kV networks.[19]

If the PBST power efficiency factor (70% reduction of fires starts when GFN technology is installed) is used for estimating the potentially avoided fire starts, then based on SA Power Networks fire start records, approximately 19 fires could have been avoided per annum, on 11kV and 7.6kV feeders in HBFRA and MBFRA, if GFN technology were installed at every zone substation.

Jacobs also concluded that even a single fire start on an extreme fire risk day in a location with hilly terrain and large quantities of dry grass and/or forest fuels, could result in another catastrophic bushfire in SA.

6. Site Selection

The proposed installation sites at Stirling East and Uraidla substations were selected based on a number of criteria including:

- Substation bushfire risk category;
- The percentage of feeders (including supplied feeders) in HBFRA;
- Feeder length;
- Total percentage of existing 11kV feeder ties to other potential GFN sites; and
- Notable items that make the substation favourable / less favourable for the implementation of GFN technology (e.g. other planned upgrade works which complement the GFN installation; cost prohibitive items; space restrictions; the

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[14] Marxsen Consulting, *REFCL Trial: Ignition Tests,* 2014, pg.30

[15] Network damping represents the amount of leakage current from conductors to earth across the network. If this value is high the rise in neutral voltage is reduced when a fault occurs.

[16] Large networks have more leakage to earth and more capacitance to earth, which makes their neutral voltage more difficult to disturb.

[17] Marxsen Consulting, *REFCL Trial: Ignition Tests,* 2014, pg.50

[18] Jacobs, *Recommended Bushfire Risk Reduction Strategies For SA Power Networks,* 2014, pg.4

[19] Jacobs, *Recommended Bushfire Risk Reduction Strategies For SA Power Networks,* 2014, pg.13

extent of ancillary works; large amounts of underground cable or covered conductor).

In the Mount Lofty Ranges, the number of Severe, Extreme or Catastrophic Fire Danger Rating days in summer has increased by between 1.7 and 2.5 times since 2000.[20] The Bureau of Meteorology (BOM) has indicated that the increased fire risk is likely to remain or increase further with increased temperature over the next five to ten years.[20] The impact of wind events, blowing material from trees onto powerlines causing shorting and loss of power, is also prevalent in the Mount Lofty Ranges.[21]

Stirling East and Uraidla substations along with their associated 11kV feeders are part of the Mount Lofty Ranges and are considered HBFRAs. High population densities within some areas of the Mount Lofty Ranges have been shown to significantly increase the consequences of a fire start[22]. Both Stirling East and Uraidla substations have an 11kV feeder that features in the top twenty high risk feeders for bushfire start.

7. Bushfire Risk Mitigation Options

7.1 Option 1 – No Additional Expenditure For Bushfire Risk Mitigation

SA Power Networks' existing disconnection capability and processes reduce, but do not eliminate, the risk of fire starts from network assets. This process only applies on extreme days and will not eliminate all fire starts. Further risk mitigation requires on-going investment in network assets.

General community expectation is that bushfire starts from electricity network assets are preventable by the network owner. Litigation against network owners has arisen from numerous bushfire events in Victoria, Western Australia and South Australia in recent years.

The VBRC (Victorian Bushfire Royal Commission) found that the events of Black Saturday called for "material reduction in the risk of bushfire caused by the failure of electrical assets". A similar expectation is likely to apply within South Australia.

Electricity asset fires are more likely to occur on extreme fire danger days, with the projected increase in frequency and extreme high temperatures, mitigation is needed to address the increased risk. This can only be achieved by undertaking prudent investment to maintain the safety and operation of electricity assets to reduce their likelihood of starting fires.

Option 1 is not recommended as SA Power Networks must ensure that it complies not only with regulations, but also with acceptable industry practice that has evolved following the extreme interstate events.

[20] Bureau of Meteorology, *Climate extremes analysis for South Australian Power Network operations*, 2014, pg.4.
[21] Bureau of Meteorology, *Climate extremes analysis for South Australian Power Network operations*, 2014, pg.33
[22] Jacobs, *Recommended Bushfire Risk Reduction Strategies For SA Power Networks*, 2014, pg.5

7.2 Option 2– Install GFNs As Part Of The Risk Mitigation Strategy Package

It is recommended that the installation of GFN technology is included in the risk mitigation strategy package as REFCL / GFN technology has significant potential to reduce the incidence of fire starts and is considered a rational economic investment. Installing the technology is prudent in order to provide hard data for fire start reduction purposes, without jeopardising public or employee safety, and to assess the installation and operational changes that would be required for roll-out in SA.

The benefits of REFCL technology outweigh the risks which can generally be addressed and mitigated.

Benefits

- Improves electrical safety and addresses consumers' top priority in relation to electricity safety and reliability by undertaking bushfire mitigation activities;

- Reduces the risk of fire start (avoiding high energy flows into the fault which creates a fire risk);

- Reduces shock hazard associated with Earth Potential Rise (EPR) at faulted pole (i.e. low risk of electrocution from fallen powerlines as a result of a reduction in voltage on downed conductors from HV levels down to very low levels (hundreds of volts).
    - SA Power Networks uses steel (Stobie) poles, under an earth fault scenario the pole remains live until supply is tripped. The REFCL Trial showed that provided the earth fault current was above 2A the GFN would detect it and actively reduce the voltage of the fallen conductor to levels less than 250V within 100ms. It has been shown that the severity of the electrocution risk is significantly reduced if the voltage on the fallen conductor is below 600V.[23]
    - Although the time interval of 10s versus less than 1s does increase the probability of the public contacting a live pole.

- There is a reduced incident of outages as a result of transient earth faults (which are self extinguishing when a GFN is used). However, this benefit is a trade off with the difficulty associated with finding permanent faults.

- Reduces plant damage/failure as the fault current and voltage are reduced at the fault location); and

- Reduces unplanned work - early detection of reduced insulation levels;

Risks

- Potential safety hazard as SA Power Networks uses steel poles; they remain live until supply tripped.

[23] Marxsen Consulting, *REFCL Trial: Ignition Tests*, 2014, pg.77.

  - May be mitigated by filtering (5th harmonics) and by ensuring the system is well tuned, accurate performance of the instrumentation and careful calibration and fine tuning of the GFN will result in a reduction of voltage at the fault location to safe levels. The standing voltage is not expected to be very high. Careful consideration of the tripping philosophy (i.e. not compensating for a permanent fault) will also ensure the risk is mitigated.

- Fundamental change in protection philosophy – major changes to how SA Power Networks manages and operate the network.
  - May be mitigated by embracing change management and involving Planning, Design, Engineering, Operators and Field Personnel in the design and development of the technology. Thoroughly testing the new design and putting it into service will also improve confidence levels and allow all groups to be involved.

- Another key part of the installations will involve a large effort required to up-skill existing staff with new skills.
  - Shift focus to the new technology, use the new projects as a training ground and make use of existing training budgets.

- Technical developmental issues and the associated unknown cost.
  - The risk associated with installing a new technology and the potential escalating cost of developing the technology can be mitigated by engaging external assistance from experienced consultants in REFCL technology. Other Australian DNSPs are also installing REFCL technology with the primary driver being bushfire risk mitigation. Drawing on their experiences and expertise will reduce the developmental issues and associated costs. The GFN manufacture is also committed to developing the product for use as a fire start risk reduction tool for the Australian market.
  - Other unknown costs include the extent of ancillary works resulting from voltage rise issues and the suitability of existing equipment (such as surge arrestors, distribution transformers and line insulators).

- High cost of ancillary works making a GFN installation cost prohibitive (indicative cost approximately $1M - $9M/substation).
  - By selecting sites that take full advantage of the bushfire risk mitigation benefits (e.g. HBFRA; significant amount of overhead cable) while minimising the amount of ancillary works will reduce the risk. For this reason, selective role-out rather than wide-spread role is the preferred strategy.
  - Synergies with other projects. Coordinating GFN installations with other substation upgrades such as installing new 11kV switchgear or installing a new control room will also reduce costs. In many cases the equipment needing modification within a substation may be due for replacement and small changes to specifications will allow it to also be used for the GFN implementation. Space restrictions within control rooms is also a significant issue so ensuring standard control rooms allow adequate space for potential GFN implementation will reduce future modification costs.

- Ongoing additional costs as network changes.

  - Taking into consideration any future feeder extension works or possible load transfers into the original design and sizing the GFN accordingly will mitigate the risk.

- Fault finding could be problematic. Conventional protection relays and line fault indicators will not detect single phase-to-earth faults as the fault current would be too low. There would be little visible evidence of the earth fault location due to the reduced fault energy. Analysis would allow the faulted feeder to be identified but the physical fault location would be extremely difficult to locate.
  - By considering a tripping philosophy that addresses fire start objectives while still facilitating fault location will address this risk. Modifying or changing other protection relays within the substation to detect and record fault data will further assist in fault location and confirmation. Further development of the GFN product and fine tuning of settings will also improve fault location capability.

- Reliably identifying the faulted feeder can pose a fire risk as the GFN requires some soil current to flow from the GFN to make the required measurements.
  - The REFCL Trial ignition tests confirmed this current can produce ground ignitions. However, expectation is that eventually suitable settings will be found to achieve the goal of ignition-free fault confirmation and faulted feeder identification.[24]

- Immature technology which requires further development. The REFCL Trial revealed that today's GFN may not prevent ignition when high current faults result in bounce ignition before the GFN has time to reduce the fault current and in this case slower ground ignition may occur[25].
  - Although today's GFN product is still in the early development stage it is still capable of delivering lower fire start risk compared to traditional technology. High impedance faults can be difficult to detect and clear. Traditional Sensitive Earth Fault (SEF) protection is generally set at 5 amps with a 5 second clearing time which is sufficient to ignite a fire. It is anticipated that further development of the GFN, including improvement of the fault sensitivity, compensation accuracy, operating speed and fault detection algorithms, will improve efficiency thus reducing bounce ignition.

- GFN equipment failure both hardware and firmware posses a risk if the GFN fails to operate as intended. Examples include failure of the Residual Current Compensator (RCC), as a result of a hardware failure or when local AC supply has tripped off, may result in the residual current rising (to say 30A during an earth fault) which has the potential for fire start. This is a particular concern as the standard SEF protection is required to be blocked when the network is resonantly grounded and standard earth fault protection is generally set no lower than 80A.
  - Ensuring the system is well tuned will ensure that the residual current will be significantly reduced even if the RCC is unable to compensate. Operating procedures can also be developed to cater for this situation to ensure the risks of failure are further mitigated.

[24] Marxsen Consulting, *REFCL Trial: Ignition Tests*, 2014, pg.29
[25] Marxsen Consulting, *REFCL Trial: Ignition Tests*, 2014, pg.8

- The GFN cannot compensate for cross country faults (simultaneous earth faults on two different phases and possibly two different feeders). This limitation results in over-voltage stress (11kV or approximately 75% greater than normal) on the healthy phases when a cross country fault occurs which increase the risk of equipment failure which can lead to fire start.
    - Cross country faults generally only occur during storm conditions. Tripping philosophies and operating procedures can be developed to address this limitation of the GFN. Further development of the GFN may also reduce this risk.

- Potential for negative reliability impact as the GFN detects high impedance faults and can initiate a trip when conventional sensitive earth fault protection would not trip and the feeder would have otherwise remained energised.
    - The likelihood of this occurring can be reduced by considering an appropriate tripping philosophy which takes into consideration bushfire risk mitigation needs as well as reliability.

- GFN / REFCL technology is limited to multi-phase feeders and therefore can not be used on SWER feeders.
    - Research shows multi-phase feeders are approximately five times more likely to start fires (per kilometre) than SWER lines[26] therefore this factor should not limit the implementation of GFN technology.

- Wide-spread equipment failure. The GFN implementation significantly changes the electrical operating characteristics of a substation and associated 11kV distribution network. Full voltage displacement occurs on the system for operation of the GFN. Over-voltage stress on the two healthy phases may lead to equipment failure. The voltage on these phases increase from 6.3kV to 11kV or approximately 75% greater than normal.
    - For the GFN technology to function, the network cannot have any phase to ground connected loads. The SA Power Networks has some phase to earth connected distribution transformers and pole mounted star connected power factor correction capacitor banks installed. Insulation of equipment and conductors must be able to withstand full line to line voltage on what is normally phase to earth insulation. To mitigate the risk of equipment failure the costs associated with replacing under-rated equipment has been included as part of the project cost. These replacement works are considered a fundamental component when adopting resonant earthing. Continued periodic assessment of the network to confirm it is sufficiently 'hardened' such that it can withstand GFN induced voltage variations without equipment failures (that lead to cross-country faults that start fires) will also mitigate the risk.

Several limitations with the GFN have been highlighted however, as the GFN technology matures it is expected that the GFN design will be capable of virtually eliminating fire risk from 'wire on ground' faults in worst case fire conditions[27]. The proposed installation sites will allow SA Power Networks to determine if the limitations identified are legitimate and pose any substantial risk.

[26] Marxsen. T, Coldham. D, Czerwinski. A, *New Research On Bushfire Ignition From Rural Powerlines*, 2012, pg.6.
[27] Marxsen Consulting, *REFCL Trial: Ignition Tests*, 2014, pg.8.

As SA Power Networks presently has no experience with the installation, operation or maintenance of GFN technology a roll-out to other select zone substations would occur only following the successful installations and in this case the GFN would be preferred over undergrounding or covered conductors due to its lower cost.

Cost Benefit Analysis

In 1983 the Ash Wednesday fires resulted in the death of 28 people in South Australia. Fires occurred at Clare, McLaren Flat, in the Adelaide Hills and in the south east of the State. The fires burnt more than 159,000 hectares of land and caused damage to several hundreds of homes in South Australia.[28] The total estimated cost of damage caused by the fires was in excess of $300 million.[29]

In 2005 the Eyre Peninsula fires that started, on a day of extreme fire danger, caused an estimated $41 million in damage, burning more than 78,000 hectares of land and causing the death of 9 people damage.[30]

The Bushfire Modelling report prepared by Willis in December 2013 estimated that the maximum probable loss (the maximum cost that could be expected from a realistic event) from fires started by SA power Networks on a given day would be two fires totalling $1.018 billion.[31]

The economic benefits associated with installing REFCL technology are enormous considering historical and modelled cost of damage caused by fires in South Australia.

Although ancillary works associated with GFN installations are relatively expensive and vary from site to site (Australian DNSP estimates range from $1M to $15M), the delivered fire risk reduction benefit per dollar spent is comparatively attractive.

Each GFN can provide protection against fire ignition from single phase to earth faults to all multi-phase (11kV) feeders in an entire substation network. SA Power Networks are likely to install GFNs at sites with between three and five 11kV feeders per bus section with each site having one or two bus sections. So there is the potential to protect up to ten 11kV feeders with one GFN.

At the two proposed sites (Stirling East and Uraidla substations) there are three 11kV feeders at each site totalling 69km and 104km of 11kV feeder respectively. The cost of the Stirling East and Uraidla GFN installations per route km is expected to be $69K/km on average. Both sites have planned upgrades in the future which will increase the number of 11kV feeders and increase the amount of 11kV feeder connected to the GFN further increasing the cost benefit.

In comparison, the cost of replacing bare conductors with underground cable or covered conductor per route km is $260K-650K/km[32] and $220K-320K/km[33] respectively. The

[28] Country Fire Authority, *Ash Wednesday Factsheet*, http://www.cfa.vic.gov.au/fm_files/attachments/kids_and_schools/fact-sheets/fs_ash-wednesday.pdf.
[29] Figure quoted in today's terms. Insurance Council of Australia, *Historical Disaster Statistics*, <http://www.insurancecouncil.com.au/industry-statistics-data/disaster-statistics/historical-disaster-statistics>.
[30] South Australia Country Fire Service, *Bushfire History*, <http://www.cfs.sa.gov.au/site/about/history/bushfire_history.jsp.
[31] Willis, *Bushfire Modelling*, December 2013, pg. 37.
[32] Jacobs, *Recommended Bushfire Risk Reduction Strategies For SA Power Networks*, 2014, pg.16.
[33] Jacobs, *Recommended Bushfire Risk Reduction Strategies For SA Power Networks*, 2014, pg.16.

effectiveness of undergrounding versus the installation of a GFN at eliminating bushfires also suggest the costs for undergrounding lines is very optimistic for some locations due to the difficulties associated with undertaking this task.

7.3 Option 3 – Invest In Alternate Bushfire Risk Mitigation Strategies

The PBST identified a range of initiatives to reduce the likelihood of powerlines starting bushfires. Many of these are applicable to SA Power Networks and are likely to now be considered as good industry practice within Australia.

The report prepared by Jacobs recommends a practical, cost-effective package of risk mitigation strategies for SA Power Networks to comply with current good industry practice.

The particular strategies and implementation options have been selected to target the issues and areas of highest fire start risk, accommodate SA Power Network's capability to execute, and provide optimum fire risk mitigation benefits at a modest cost.

Consumers top two electricity safety and reliability priorities, according to independent consumer consultations, were bushfire mitigation activities and maintaining electricity infrastructure[34]. Consumers' most preferred bushfire management initiative included building powerlines that are less prone to starting fires.[35] Support for increased standards is also high with 72% of electricity consumers strongly supporting SA Power Networks increasing its inspection, maintenance and construction standards in bushfire risk areas to reduce the risk of fire starts from powerlines.[36]

If the REFCL / GFN installation is removed from this package then SA Power Networks will still be in a position to reduce the incidence of fire start by installing alternate fire start reduction strategies. Including installation of electronic SCADA reclosers; replacement of RAGs (rod air gaps) and CLAH (current limiting arching horns) with surge arrestors; and targeted replacement of bare conductor with the Hendrix system on 11kV and 33kV lines. However, the potential of REFCL / GFN technology cannot be realised by SA Power Networks without undertaking the proposed installations. The GFN has the potential to be a cost effective tool to aid in the prevention of fire starts and investment is needed to quantify the cost and benefits of this technology. As such option 3 is not recommended.

8. Scope Of Work

The scope of substation works consists of the design, procurement, installation and commissioning of the civil works, primary plant, secondary equipment, protection and control modifications and auxiliary works.

The scope of the 11kV feeder works consists of the design, procurement, installation and commissioning of surge arrestors, distribution transformers, line insulators, admittance balancing modules and protection modifications of reclosers (ACR's). A contingency fund to be used for stress testing of equipment with replacements and the installation of 5th harmonic filtering (as required) has been included.

[34] Deloitte, *Online Consumer Survey*, July 2013, page 7.
[35] Deloitte, *Online Consumer Survey*, July 2013, page 47.
[36] Deloitte, *Online Consumer Survey*, July 2013, page 48.

9. Implementation Strategy

The proposed GFN Implementation strategy includes:

1. Install GFN at two adjacent substations in HBFRA to assess the extent of network conversion required and to gain operational experience and test all the risks identified and refine suitability of mitigation strategies.

2. Install GFN at targeted substations in HBFRA where the fire risk is deemed extreme in following Regulatory periods.

3. Install GFN at targeted substations in MBFRA where the fire risk is deemed High based on risk benefit in following Regulatory periods.

10. Recommended Solution for 2015 - 2020

To install REFCL / GFN technology as a strategy for bushfire risk mitigation it is recommended that funds are allocated for the implementation of stage 1 of the GFN implementation strategy. Due to the complexity associated with costing the implementation an allowance of $12M has been requested based on experience and knowledge of costs incurred by Victorian utilities when implementing the same technology.

The project is forecast to be fully implemented within the 2015 to 2020 regulatory period.

It is expected to take several years after the first REFCL installation for engineers and operations staff to gain sufficient understanding and overcome immediate challenges of the available technology. With the knowledge and understanding gained from the proposed installations and with improvements in the available technology the benefits of REFCL technology are expected to be embraced and technical issues will decrease.

11. Attachment A - References

1. SA Power Networks, *South Australia Power Networks Regulatory Proposal 2015–20 Attachment 20.50: Bushfire mitigation summary,* 2014.

2. Powerline Bushfire Safety Taskforce, *Final Report*, September 2011. ESV website, 30th September 2011, http://www.esv.vic.gov.au/Portals/0/About%20ESV/Files/RoyalCommission/PBST%20final%20report%20.pdf

3. Jacobs, *Recommended Bushfire Risk Reduction Strategies For SA Power Networks,* 2014.

4. Marxsen Consulting, *REFCL Trial: Ignition Tests,* 2014. Report prepared for United Energy.

5. HRL Technology for Energy Safe Victoria, *Probability of Bushfire Ignition from Electric Arc Faults, Final Report, Report No: HLC/2010/195*, December 2011.

6. Marxsen. T, Coldham. D, Czerwinski. A, *New Research On Bushfire Ignition From Rural Powerlines*, 2012. Published in the magazine T&D, February/March 2012.

7. Bureau of Meteorology, *Climate extremes analysis for South Australian Power Network operations,* 2014.

8. Deloitte, *Online Consumer Survey*, July 2013, page 7.

9. Willis, *Bushfire Modelling,* December 2013.

10. Parsons Brincherhoff (on behalf of the Powerline Bushfire Safety Taskforce), *ESV Powerline Bushfire Safety Review – Cost Benefit Analysis,* September 2011.

11. Powerline Bushfire Safety Taskforce, Final Report, September 2011.