Jemena Electricity Networks (Vic) Ltd

Replace Coburg South (CS) Zone Substation Aged Relays

Business Case

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Replace Coburg South (CS) Zone Substation Aged Relays

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PREFACE

The intent of this business case document is to provide self-supportive, rigorous documentation to substantiate the need and prudency of an investment for both JEN and its customers. The business case should assist in determining the strengths and weaknesses of a proposal, in comparison with its alternatives, in a systematic and objective manner. The business case seeks endorsement and funding for the project from the appropriate JEN stakeholders and approval from the relevant delegated financial authority.

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1. EXECUTIVE SUMMARY

Synopsis

- Purpose of this project is to mitigate risks of asset damage and health and safety risks, and to maintain reliability and security of supply of standard control services from Coburg South (CS) zone substation to more than 23,992 customers. The risks are due to deteriorating secondary system equipment infrastructure.
- The most efficient option has been chosen from a life cycle ownership perspective as guided by the Asset Class Strategy document.
- The project is planned to commence in 2024 and be completed in 2026, at an estimated cost of $7,456k (total project cost, real $2019).

1.1 BUSINESS NEED

This business case relates to mitigation of risks associated with deteriorating protection and control infrastructure at the Coburg South (CS) zone substation.

This project is necessary to:

- Maintain the performance of the protection asset class in accordance with accepted practices world-wide and JEN's asset management policies, given the critical role of protection relays in managing fault clearance in electricity network;
- Mitigate health and safety risks to personnel and / or the community to As Low As Reasonable Practicable (**ALARP**) principle;
- Mitigate risk of asset damage; and
- Maintain reliability of electricity supply to over 24,000 customers being served from CS zone substation

The project is planned to commence in 2024 and be completed in 2026, at an estimated cost $7,456k (total project cost, real $2019).

1.2 RECOMMENDATION

The proposed Option 3 is recommended to be endorsed. This option consists of replacement of deteriorating protection and control equipment and the associated asset with modification to the existing control building at CS to house all new equipment, in the period 2024-2026, at an estimated cost of $7,456k (total project cost, real $2019).

This option is preferred based on following considerations:

- It recognises the critical role of protection relays in keeping the electricity network safe by timely clearance of network faults;
- It facilitates managing the health and safety risks to personnel, associated with deteriorating protection system assets, to As Low As Reasonably Practicable;

- It enables protecting the major assets such as power transformers; 66kV buses and 22kV buses etc from damage due to network faults;
- It ensures maintaining the current performance level on reliability of electricity supply to over 24,000;
- It enables JEN to maintain supply of standard control services (**SCS**) from Coburg South (CS) zone substation as an efficient and knowledgeable operator should;
- It is technically prudent and addresses the risks identified, and it reduces the possibility that JEN would be found to have breached its general obligations associated with good asset management;
- It is in line with JEN approach of considering end-of-life replacement of assets with due consideration to useful life [1] and asset condition;
- It is in accordance with JEN's protection and control asset class strategy[2] and JEN's broader corporate objectives.

1.3 REGULATORY CONSIDERATIONS

There are no specific legal obligations that the protection infrastructure at CS is expected to breach. However, the occurrence of serious incidents due to the issues discussed here increase the possibility that JEN could be found in breach of its broader obligations associated with its protection and control systems and its requirement to apply good asset management.

In this regard, the two most significant obligations are:

National Electricity Rules (Version 66), section 5.1.9, Protection systems and fault clearance times

C. *Subject to clauses S5.1.9(k) and S5.1.9(l), a Network Service Provider must provide sufficient primary protection systems and back-up protection systems (including breaker fail protection systems) to ensure that a fault of any fault type anywhere on its transmission system or distribution system is automatically disconnected in accordance with clause S5.1.9(e) or clause S5.1.9(f).*

Victorian Electricity Distribution Code (Version 7 – May 2012), section 3.1, Good Asset Management

A distributor must use best endeavours to:

A. *assess and record the nature, location, condition and performance of its distribution system assets;*

B. *develop and implement plans for the acquisition, creation, maintenance, operation, refurbishment, repair and disposal of its distribution system assets and plans for the establishment and augmentation of transmission connections:*

   a. *to comply with the laws and other performance obligations which apply to the provision of distribution services including those contained in this Code;*

   b. *to minimise the risks associated with the failure or reduced performance of assets; and*

[1] JEN Network Asset Useful Lives Procedure (ELE PR 0012)

[2] Zone Substation Protection and Control Equipment Asset Class Strategy (JEN PL 0021)

c. *in a way which minimises costs to customers taking into account distribution losses; and*

C. *Develop, test or simulate and implement contingency plans (including where relevant plans to strengthen the security of supply) to deal with events which have a low probability of occurring, but are realistic and would have a substantial impact on customers.*

1.4 FINANCIAL INFORMATION

1.4.1 FORECAST EXPENDITURE AND BUDGET SUMMARY

This business case proposes a total investment of $7,456k (total project cost, real $2019) and requires Managing Director's (B and B) approval under the SGSPAA DFA Manual, Annex 3.

The business case is prepared in relation to regulatory submission for the period 2020-2026.

This project is required to be completed by 2026.

Summary of financial analysis of the recommended option (Option 3) is provided below:

Table 1-1: Project Budget Information

Budget Value	Total ($'000s, $2019)
CAPEX Budget	6,346
Overhead Recovery	1,110
Total Budget Value	**7,456**

2. BACKGROUND

2.1 BUSINESS AND SOCIO ECONOMIC CONTEXT

CS zone substation was constructed in the 1970's. It has two 20/30MVA transformers and supplies electricity to 23,992 customers via eight 22 kV feeders and a capacitor bank. There are mainly domestic and industrial customers being supplied via CS. Major customers supplied from CS include MMTB (Tramway Substations). There is no significant co-generator connected to CS.

2.2 ASSET RISK (OR OPPORTUNITY) ANALYSIS

2.2.1 SHORT DESCRIPTION OF THE AFFECTED JEN ASSETS

The protection infrastructure at CS zone substation consists of a mix of various generations of relays – from electromechanical to next generation analogue and the modern digital relays. From the Secondary System perspectives, CS has various patchy upgrade/modification to the protection and control relays since the first installation in year 1976. All upgrade works were kept to the legacy design practice. Most of these relays have passed their useful lives. They do not comply with the present JEN standards and are not suitable for the latest reporting regimes.

Many existing protection schemes such as transformer HT overcurrent protection, transformer control, Back up transfer trip scheme, 22kV bus overcurrent protection scheme and Capacitor bank protection etc. are all made up of relays that are 42 years old and are beyond their useful life. Maloperation and/or failure to operate of these relays will cause the loss of supply to one electricity bus (affecting over 11,000 customers) or even total loss of station supply (23,992 customers). Severe damage to major assets such as the power transformers, and safety to employee and general public is a risk if system fault cannot be detected and cleared by protection equipment.

Current useful life of electromechanical relays is 40 years and that of analogue and digital relays is 20 years.[3] The asset useful lives are based on good industry practice and the specific JEN experiences, and represent the lives of assets at which end-of-life replacement will be considered.

This section enumerates the issues and related risks with regard to the current state of the protection and control systems at CS. In accordance with the North American Electric Reliability Council (**NERC**)'s Protection System Maintenance Technical Reference[4], *"Protective relays have been described as silent sentinels, and do not generally demonstrate their performance until a fault or other power system problem requires that they operate to protect power system elements…A mis-operation - a false operation of a protection system or a failure of the protection system to operate when needed - can result in equipment damage, personnel hazards, and wide area disturbances or unnecessary customer outages".*

The above statement of NERC emphasizes the main role of protection system in protecting the assets from damage and ensuring safety of personnel during a fault situation. These aspects are closely meshed with reliability and integrity of systems.

A range of issues at CS are impacting JEN's ability to meet or maintain the reliability and security of supply of the Standard Control Services (**SCS**) as stipulated in the National Electricity Rules (NER).

[3] JEN Network Assets Useful Lives Procedure (ELE PR 0012)

[4] North American Electric Reliability Council (NERC)'s Protection System Maintenance - A Technical Reference (September 13, 2007) - Prepared by the System Protection and Controls Task Force of the NERC Planning Committee

2.2.2 RISK ASSESSMENT

Protection failure can lead to following consequences:

- Increased health and safety risk to personnel
- risk of asset damage due to prolonged fault clearance and higher energy let through (I^2t) causing stress to assets
- Impact on reliability of electricity supply

Consequences of both primary and back-up protection failures can be costly, as evidenced by the recent protection scheme failures at Morwell Terminal Station where on 4 April 2014 failures of both protection schemes on a line during a fault on the line led to loss of supply to 80,000 customers in Gippsland.

Energy Safe Victoria (**ESV's**) Morwell Terminal Station Incident Final Report summary excerpt reads[5]:

> *"ESV understands that this event will affect the service component of AusNet Services' transmission STPIS with a total marginal impact likely to be in excess of $1M. The associated costs of repair and reconstruction are also likely to be significant.(… 1865 route meters of 66 kV conductor… pole top assemblies on poles 2, 3, 4, and 5…replacement of a 22 kV gas switch…)*
>
> *ESV's investigation confirmed… The probability of the sequence of events that occurred on 4 April, where both of the primary protection schemes failed to operate, is considered low but not impossible".*

This incident demonstrates the severity of consequences of protection schemes failing to operate, when required under network fault conditions.

The issues discussed here and the proposed solutions are part of JEN broader Protection and Control systems strategy. These matters are discussed in ZSS Protection and Control Equipment Asset Class Strategy (JEN PL 0021).

2.2.2.1 Degradation of reliability of supply, risk of asset damage and health and safety risk due to majority of relays being electromechanical type and without failure monitoring and without spares

Many relays at CS are the oldest generation - that is electromechanical type. These relays have long been discontinued by manufacturers. There are no spares available for these relays. These relays are being used for protection of assets like transformers, buses and Capacitor banks.

Background:

Electro-mechanical relays are the oldest relay technology. They comprise moving parts, springs and magnets that degrade their characteristics over time, affecting the relay performance.

These relays do not provide diagnostics or health monitoring; hence, a failure may remain hidden.

Relays retired from service at other stations are kept as spares, and parts cannibalized to maintain in-service relays, so that there are some relays at CS that as well as being old, have been refurbished with older parts. The spare relay stocks are now exhausted such that further electro-mechanical relay failures there is no exact spare and the whole protection scheme would need to be modified.

[5] Energy Safe Victoria's (ESV) Morwell Terminal Station Final Report (August 2014) – Regulatory Regime section

Consequence:

Electromechanical relays do not have failure monitoring; hence a relay failure may remain hidden, thus increasing the risk of fault not being cleared. These relays do not provide fault diagnostics such as disturbance records and distance to fault information; this results in increased time in troubleshooting, fault location and fault investigations. Further, increasing lack of spares directly impacts the availability of protection schemes having electromechanical relays.

These issues impact JEN's ability to meet the obligations under Section 5.1.9 of the NER, notably the obligation related to clearance of faults. Further, this exacerbates health and safety risk and increases possibility of asset damage due to faults not being cleared in a timely manner.

The continuance of these relays in the network is impacting the reliability of supply to customers, health and safety risk and asset damage risk.

2.2.2.2 Degradation of reliability of supply, risk of asset damage and health & safety risk due to failure of SR family type relays failures

SR745 relays are installed at CS. These relays are the same vintage as the SR760 where JEN has experienced numerous failures. These two models of relay from GE-Multilin are built on the same SR relay platform and are now beginning to exhibit the same failure mode. This failure mode exposes JEN to risks associated with personnel H&S, asset damage and reliability of supply. There were 2 failures of SR745 relays at JEN's zone substations BY and SHM. The failure mode is same as exhibited in SR760 relays where JEN has experienced a total of 19 instances of failure. A program has been initiated to progressively replace these relay types.

Consequence:

Feeder protection relays are required to protect the feeder and to operate during a fault on that feeder; during this, the supply is lost to the customers connected to that feeder. When a feeder protection relay fails to operate during a fault, the back-up protection (bus bar protection) operates to clear the fault.

Relying on backup protection to clear the fault has following sub-optimal consequences:

- **Increased possibility of serious injury or fatality** – Back-up protection is designed to take longer time to clear the fault, and consequently, the fault and fault current remain on the network for longer period. Therefore, there is a greater possibility that assets carrying the higher fault current could cause serious injury or fatality to JEN personnel and general public.
- **Increased possibility of asset damage** – Due to the longer time taken by the backup protection to clear the fault, there is a greater possibility that assets carrying this higher fault current may be stressed, damaged and may have impact on design life.
- **Increased customer outages** - The number of customers that will lose supply will increase because the backup protection isolates a wider section of the network. In the case of a feeder fault, the backup protection will result in loss of supply to all customers supplied by that bus, rather than just those customers supplied by the faulted feeder.

The consequence of SR type relay failure is that they will not operate to clear the fault exposing JEN to risks associated with personnel H&S, asset damage and reliability of supply, The power supply module fails due to capacitor component dying out. This failure mode has also been experienced in other analogue relays such as SPAJ140C. very similar to those of SPAJ140C type relay failures where the power supply module failed due to capacitor component drying out. There is also lack of complete monitoring of all DC rails that leads to non-reporting of invalid measured data, hence it may mal operate or fail to operate.

An example of failure of SR760 type relays occurred on 16 January 2014, where the relay failed to operate for a fault on feeder ST34. On this occasion, the back-up bus protection operated to clear the fault. Consequently, supply to all feeders on the 22 kV No 3 bus was lost affecting 9,038 customers.

Continuing to use SR type relays at CS is likely to worsen the reliability of supply to customers as well as heightens the risk of asset damage.

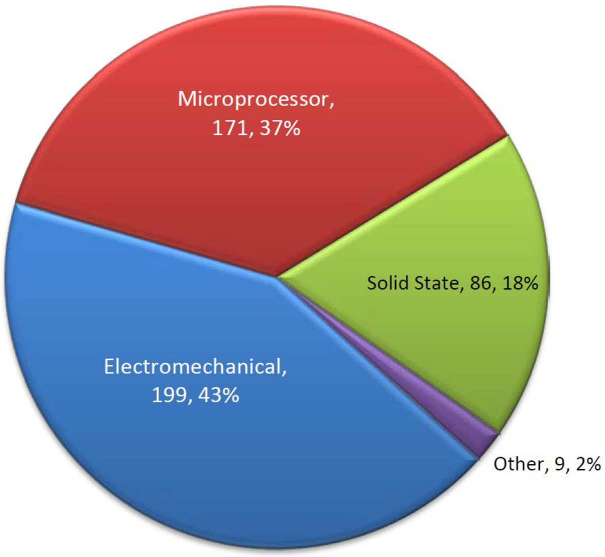
This issue impacts JEN's ability to meet the obligations under Section 5.1.9 of the NER, notably the obligation related to clearance of faults.

2.2.2.3 Degradation of security of supply due to deteriorating and unmonitored duplicate protection schemes

In a number of protection schemes at CS, both X and Y protection relays are of electromechanical type. Such schemes include transformer protection, 22 kV bus protection. These relays do not have self-monitoring or alarming feature resulting in potentially hidden failures with consequences. Also the operating mechanisms and components within these relays deteriorate with time (e.g. due to loss of magnetism). A latent fault will not be apparent until detected by maintenance or investigation following a mal-operation.

NERC have conducted several studies on relay mis-operations and the relay technology (microprocessor, analogue or static, electromechanical). In a NERC survey-cum-study titled NERC Protection System Mis-operations Task Force Report, April 2013[6], a survey was carried out on a relay population consisting of predominantly numerical relays (66% of total population), and it was found that as high as 43% of total relay mis-operations occurred involving electromechanical relays (refer figure below).

Figure 2-1: NERC Wide Mis-operations by Technology Type (for Relay Failures Cause Only)



Note, JEN has only recently started to capture the fault history of all types of relays in SAP. As such, JEN currently does not have a sizeable database of the history of relay failures. Meanwhile, based on above global analysis of relay mis-operations conducted by NERC, it can be stated that the industry experience is that the electromechanical relays have been found to be more prone to mis-operations than numerical or analogue relay types.

6 North American Electric Reliability Council (NERC) - Recommendation Report - Prepared by: Protection System Mis-operations Task Force (April 1, 2013)

Consequence:

Electromechanical relays present situations where reliability of supply can be impacted:

When both X and Y protection schemes consist of electromechanical relays (e.g. bus X & Y protection schemes at CN consisting of CDG11 and CDG 14 relays respectively), there is a possibility that both X & Y protection relays may have failed without knowledge of operating personnel, thus putting the substation assets at risk of damage in the event of a fault, and also impacting the safety of personnel. Although not very common, such a possibility presents a credible scenario. For example, at AusNet Services' Morwell Terminal Station (**MWTS**) on 4 April 2014, both X & Y protection schemes failed which led to a flashover and loss of supply to 80,000 customers in Gippsland.

In a publication of the Institution of Electrical and Electronics Engineers (**IEEE**) entitled **Working Group C-6, System Protection Subcommittee**

IEEE PES Power System Relaying Committee Final Report on Wide Area Protection and Emergency Control[7]**,** the importance of undetected relay failures is highlighted in these words: *"It has been observed that of all the reported cases of major system blackouts (wide area disturbances) in North America, about 70% of the cases have relay system contributing to the initiation or evolution of the disturbance. On closer examination, it became clear that one of the major components of relay system mis-operations is the presence of relays which have failed during service, and their failure is not known. Consequently, there is no alarm, and no repairs or replacements are possible. These hidden failures are different from straight relay mis-operations, or failures which lead to an immediate trip. The hidden failures remain undetected (and substantially undetectable), until the power system becomes stressed, leading to an operating condition which exposes the hidden relay failures".*

Electro-mechanical relays can have hidden failures that may either cause non-operation in the event of a fault or operate under load and non-fault conditions. In either event, consequences can cause supply disruption.

This issue impacts JEN's ability to meet the obligations under Section 5.1.9 of the NER, notably the obligation related to clearance of faults.

2.2.2.4 Safety risks to people due to failing protection relays

Purpose of protection systems is to protect assets and minimise risk of injury to people to ALARP, by effectively clearing network faults, and maintain reliability of supply to customers. Failure to do so may lead to serious risk to operating personnel and the public due to possibility of following:

1. electrocution from direct contact with energised conductors;
2. hazardous step and touch potentials;
3. start of fire from downed conductors or conductors contacting dry vegetation during high winds and high temperature conditions.

The issue of personnel safety is linked to JEN's obligations under Section 3.1 of the Electricity Distribution Code "*to minimise the risks associated with the failure or reduced performance of assets".*

In 2013, a contractor working on a scaffold came into contact with conductor of feeder BY13 in Braybrook area. Feeder protection for BY13 correctly detected this fault and isolated the fault by tripping BY13 CB. However, this was not enough to save the life of the person who came into contact with the feeder conductor, because the technology available at this stage and requirement of supply reliability limits feeder protection's capability to operate faster.

[7] Institute of Electrical and Electronics Engineers (IEEE) report entitled Working Group C-6, System Protection Subcommittee IEEE PES Power System Relaying Committee Final Report - Wide Area Protection and Emergency Control – (section on Relay Hidden Failures)

On that day, had the feeder protection failed to clear this fault, there could have been more fatalities and JEN could possibly have been found liable for the loss of life because the primary protection failed to clear the fault. This event amply demonstrates how critical it is to maintain the protection systems in sound condition at all times.

In a report prepared by the Institute of Electrical and Electronics Engineers (**IEEE**) entitled Redundancy Considerations for Protective Relaying Systems[8], the purpose of protection relays has been accentuated as follows:

"Because protective relaying provides no profit and is only required for infrequent and random abnormal operation of the power system, it can be described as insurance that prevents damage to the main grid equipment while minimizing outage time".

Due to the critical aspect of protection systems in minimizing asset damage and also keeping personnel safety to ALARP level, protection relays are not run to failure and reasonable steps are proactively taken to keep the protection system in sound health at all times.

The table below provides a summary of above outlined issues and their consequences:

Table 2-1: Summary of issues and consequences

ISSUE	Consequence
Old generation relays in network, without spares	Reliability of supply of SCS impacted
Abnormal operation of relay	Additional operational costs in troubleshooting and replacing
Obsolescence of relays and lack of spares /support from manufacturers	Reliability of supply of SCS impacted
Both X & Y protection schemes unmonitored (electromechanical relays)	Security of supply of SCS impacted
Prolonged fault clearance time due to protection relay failure	Longer fault clearance times leading to increased risk of damage to assets due to high energy let through (I^2t)
Health and safety risks due to failing and deteriorating relays	Safety of personnel impacted

There is a business requirement to address above issues of deteriorating condition of relays infrastructure.

The project is planned in the period 2024-2026, based on following considerations:

- due to the condition of the ageing and deteriorating assets, the estimate of financial impact of consequences on account of S factor impact is of the order of $0.80M per annum;
- age and condition of relays infrastructure has deteriorated to a point where JEN's ability to deliver SCS may be impacted;
- this project will enable JEN in keeping the risks arising from deteriorated and ageing assets to below ALARP level

The optimal timing for the commencement of the project is 2024.

[8] Institute of Electrical and Electronics Engineers (IEEE) - IEEE PSRC, WG I 19 - Redundancy Considerations for Protective Relaying Systems

2.3 PROJECT OBJECTIVES AND ASSESSMENT CRITERIA

Project objectives

This project seeks to meet the key objective of maintaining the standard control services as set out in the NER.

The proposed capital expenditure will meet the following objectives, as set forth in NER 6.5.7 (3) sub clauses (iii) and (iv):

- Mitigate risks associated with asset damage due to deteriorating condition of protection relay infrastructure at CS
- Mitigate health and safety risks to personnel
- Maintain the quality, reliability and security of supply of standard control services
- Maintain the reliability and security of the distribution system through the supply of standard control services

In summary, this project aims to mitigate risk of asset damage, health and safety risks to personnel and to maintain the reliability and security of the distribution system by mitigating the issues outlined above

Assessment criteria

The assessment criteria by which the project will be assessed against are the extent to which each of the identified options addresses the issues, as described in Section 2.2. Valid options that address the critical issues described therein are then analysed from both net present value and network risk perspective, in order to determine the preferred option.

2.4 CONSISTENCY WITH JEN STRATEGY AND PLANS

JEN's focus is to improve its competitiveness and adaptability in the following ways:

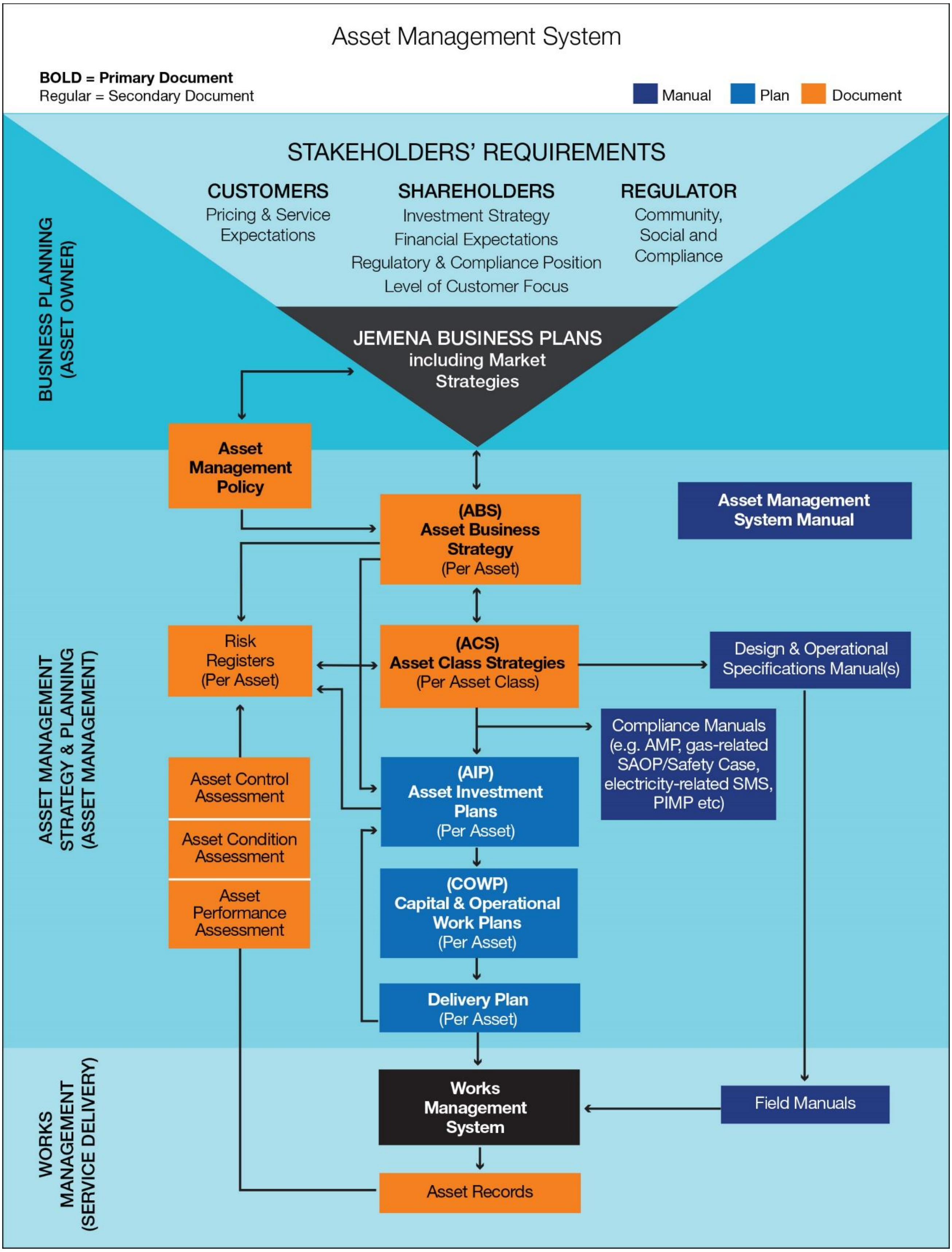
1. Efficiently and safely deliver affordable and reliable energy;
2. Make the customer experience easier and more valuable through digital and performance improvements; and
3. Modernise the grid to prepare for a connected future.

This project is based on guidelines and principles enshrined in the JEM AM Secondary Plant Asset Class Strategy.

Figure 2-2 outlines the JEN asset management system and where the Asset Management Plan (**AMP**) is positioned within it. The AMP covers the creation, maintenance and disposal of assets including investment planned to augment network capacity to meet increasing demand and to replace degraded assets to maintain reliability of supply to meet JEN Business Plan requirements.

This strategic framework facilitates the planning and identification of business needs that require network investment documented via business cases.

Figure 2-2: The JEN Asset Management System



3. CREDIBLE OPTIONS

This section discusses how credible options are identified and developed. The credible options are considered for their commercial and technical feasibility, abilities to address the identified needs, deliverability, economic and financial benefits, as well as legal and regulatory implications.

3.1 IDENTIFYING CREDIBLE OPTIONS

The following options were considered to address the business need, problem or opportunity:

3.1.1 OPTION 1 – DO NOTHING

Option 1 represents a continuation of the existing regime for maintenance and replacement upon failure of these secondary system assets, without any further actions.

3.1.2 OPTION 2 – INCREASE MAINTENANCE

Option 2 represents a change to the existing maintenance regime for these equipment, with the aim of reducing the likelihood of failure. The change will involve increasing the frequency of equipment maintenance from once in 8 years to once every year.

3.1.3 OPTION 3 – BULK RELAY REPLACEMENT USING DIGITAL SUBSTATION TECHNOLOGY

Option 3 involves proactive and planned replacement of the protection and control infrastructure, using IEC61850 standard including features of digital and smart substation technology.

3.1.4 OPTION 4 – PIECEMEAL REPLACEMENT OF PROTECTION AND CONTROL RELAYS

Option 4 involves replacement of relays in a number of lots, each lot consisting of relays which have been failing and other relays nearing end of useful life.

3.1.5 OPTION 5 - NON NETWORK OPTION

Option 5 involves seeking solutions to the identified issues outside JEN.

3.2 DEVELOPING CREDIBLE OPTIONS COSTS & BENEFITS

The credible options are discussed in the following sub-sections.

3.2.1 OPTION 1: DO NOTHING

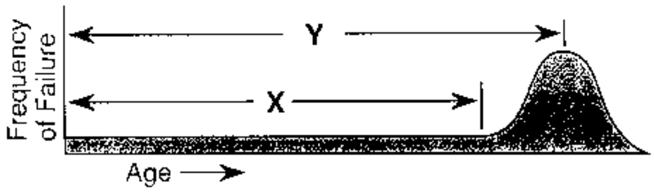
Option 1 represents Do Nothing scenario - that is, maintaining the status quo.

3.2.1.1 Scope, costs & timelines

Option 1 is the base case and represents the Do Nothing option, which means, continue the routine maintenance and replace relays upon failure, at the CS Zone Substation. Under this option, relay equipment will undergo routine maintenance every 8 years and will be replaced only when non repairable relay failure is detected.

Replacing relays upon failure poses risk of loss of electricity supply to customers, which is not acceptable (for example, supply to over 14,000 customers could be lost, if a bus protection relay mal-operated , or over 24,000 customer if bus protection relay did not operate.

Probability of failure of protection relays follows Weibull distribution, as given below:



The failure rate of relays increases steeply as the relays reach end of useful life.

Protection relay failure has following consequences:

- damage to network assets;
- possible injury to personnel; and
- unnecessary network interruption to a large number of customers as discussed earlier

The current condition of many protection and control relays has already passed the end of useful life at the CS zone substation. In addition, relays of similar make and model as at CS have also been failing at other zone substations across JEN. The likelihood of failure will continue to increase until a solution is implemented.

This option has following consequences:

- it is expected to continue to adversely impact JEN's ability to maintain delivering standard control services (**SCS**); and
- this option will continue to increase the risks of asset damage, health and safety risks to personnel and to affect network reliability performance and would compromise JEN's ability to meet the requirements of the Victoria Electricity Distribution Code

3.2.1.2 Assumptions and forecasts

Financial evaluation for this option was carried out by considering the following:

- Health and safety risk
- Mal-operation of bus or transformer protection relays to operate during network fault and impact on STPIS
  - feeder fault leads to operation of protection upstream which leads to loss of supply to all customers connected to a bus (expected supply restoration time considered as 1 hour)
- Failure operation of bus and transformer protection relays and impact on STPIS
  - Possible excessive damage to major plant such as power transformer and bus.
- Failure of Master Earth Fault relay to operate during network fault and impact on STPIS

- failure of Master Earth Fault protection relay to isolate fault leads to operation of back-up protection which leads to loss of supply to all customers connected to a bus (expected supply restoration time considered as 1 hour)

In above computations, it is assumed that the probability of failure of protection relays which have outlived their design life is 45%.

3.2.2 OPTION 2: INCREASE MAINTENANCE

3.2.2.1 Scope, Costs & timelines

Option 2 comprises an increase in the frequency of relay maintenance from once every 8 years as per current practice, to once every 12 months.

This option has been considered on the premise that an increased maintenance may bring to notice certain hidden failures in equipment and therefore bring about some reduction in probability of network faults not being cleared by protection equipment due to those failures.

The impact of increased maintenance on the reliability of various generations of relays is further elaborated below:

- Numerical and analogue (static) relays:

  Numerical and electronic relays consist of electronic and microprocessor based components and practically no maintenance can be carried out at this component level. However, during maintenance some components (e.g. relay output contacts) can be checked for failures. Note such failures are not possible to be flagged under self-diagnostics or alarming in older relays. Thus increased maintenance when a relay type is known to have reliability issues can verify the relays' operability at one point in time, there is little guarantee that a component failure will not occur within a short time.

- Electromechanical relays:

  Electromechanical relays have springs, bearings and magnets that under maintenance can be adjusted to bring the relay to within calibration. Once calibrated, reliable operation for some time can be assumed, but if the limits of adjustment are reached then continued degradation will occur. If a type problem becomes known (spring corrosion) then increased maintenance can detect the problem before failure under network faults occur.

This option, however, has following consequences:

- Limitations of this option: (a) hidden failure of relay for maximum of 1 year period, (b) limited maintenance possibility
- An increase in maintenance activities within the existing control building would also increase the health and safety risks associated to the extent that these works will entail working in the constricted space and on or in vicinity of panels with asbestos. This represents a qualitative adverse impact on personnel health and safety.
- Ad hoc relay replacement would continue to occur upon failure. The installation of new relays into existing legacy design would be expensive, time consuming and in many cases may not be even practicable.
- It may provide some increase in the useful life of electromechanical relays; however, there is added risk of disturbing the old deteriorating operating mechanisms within these relays and thus introducing more issues in the relay circuits.

This option is technically feasible and hence, it has been considered for further evaluation.

3.2.2.2 Assumptions and forecasts

Financial evaluation for this option was carried out by considering the same failure scenarios and impacts as Option 1.

It is considered that under Option 2, although there is no material impact on the design life of the secondary system assets, there is a possibility of some obvious defects being known in course of increased maintenance, which may marginally reduce the probability of failure of protection relays (it has been assumed that probability of failure marginally improves from 45% for Do Nothing option to 40%).

3.2.3 OPTION 3: BULK RELAY REPLACEMENT USING DIGITAL AND SMART SUBSTATION TECHNOLOGY

3.2.3.1 Scope, costs & timelines

Option 3 proposes the bulk replacement of all protection and control relays at the CS zone substation

This option has the consequence of capital investment; nevertheless this option provides following benefits:

- Risk of damage to network assets is maintained;
- Risk to personnel (associated with failure of secondary system assets) is maintained and not worsened;
- Risk of supply interruption to customers is maintained and not worsened; and
- Reliability of supply of SCS is maintained

The benefits in mitigating risks of asset damage, health and safety risks to personnel and in maintaining reliability of electricity supply to customers and maintaining personnel safety are primarily based on the reduction in likelihood of relay failure after replacement of ageing and deteriorating relays.

Together with replacement of primary switchgears (separate project) and the planned bulk replacement of the aged, deteriorating protection relay infrastructure at CS, this would provide an opportunity to implement JEN secondary design standard that is normally not achievable in simple like for like replacement due to lack of suitable primary sensors such as current transformers and voltage transformers. This enables optimising the types of secondary system assets in JEN and bringing uniformity to the installed asset base. This would help in realising operational cost benefits (due to factors such as optimisation of spares) and would lead to further savings in cost of electricity supply to customers.

The existing construction style of CS is that all Primary Switchgear and Secondary Equipment are into one building. There is no real estate available for construction of a new control room. Given the limited space availability and arrangement of panels in existing control room, presence of asbestos in the building, this option requires a major rearrangement to accommodate all new equipment in control building. This option will present logistical complexities which will require additional resources for planning and project implementation, however, it is achievable and can deliver a good project outcome with good project management.

This option is based on utilising the digital substation technology (IEC 61850 standard) and the digital smart zone substation technology. In 2013, JEN adopted a strategy to implement digital substation technology in relay replacement projects with the objective to embrace new technology and realise lower project costs in the long term. JEN will complete a project at Preston (PTN) using similar digital technology and IEC 61850 standard.

3.2.3.2 Assumptions and forecasts

Financial evaluation for this option was carried out using the current financial evaluation template.

3.2.4 OPTION 4: PIECEMEAL REPLACEMENT OF PROTECTION AND CONTROL RELAYS

This option proposes piecemeal replacement of relays in a number of lots, each lot consisting of relays which have been failing and other relays nearing end of useful life.

There are a number of major limitations and risks in pursing this option, which are described herein below.

- Protection and control relays are highly integrated within the protection and control schemes. A piecemeal replacement would result in sub-optimal designs and implementations. In some instances, due to legacy nature of existing schemes, long outages may be required to have access to parts of schemes, thus impacting supply of electricity to customers.
- The replacement relays are digital relays which require different auxiliary DC bus requirement and communication arrangement for application of JEN standard. A piecemeal replacement approach will have a major impact to the existing arrangement which may lead to incorrect protection operation.
- Operation of a hybrid system, consisting of old legacy schemes, with new schemes would be complicated and confusing to field personnel. This may require substantial training and upskilling, but nevertheless, increase risk of human error in operation of the substation, thus impacting supply of electricity to customers.
- This approach would thus prevent from utilising the economies of scale associated with a bulk relay replacement and accordingly does not reflect an efficient use of resources.
- Mobilisation costs and project overheads would be duplicated several times.
- Due to staggered replacement of relays, volume discounts for equipment purchases may not be realised.
- Many of the relay panels at CS contain asbestos and any cutting or drilling work is required to be carried out under stringent conditions including a breathing mask, full cover protective clothing, vacuum collection of dust produced and correct environmental disposal.
- Due to the ad-hoc nature of staggered replacement, this option presents a scenario of being unplanned and therefore, resources may not be available in time for implementing the ad-hoc replacements intrinsic to this option.
- Major equipment modification on a live system in a brown-field project situation is well known to have inherent risks which would need to be quantified and managed, which will entail additional costs.
- Modification of protection and control schemes within existing control building (which has a cramped limited-space working environment) represents health and safety risk that could be unacceptable and may easily result in human error, which could potentially lead to interruption in electricity supply to customers.

On account of above described limitations and inherent risks, Option 4 was not considered technically feasible and will not be pursued any further.

3.2.5 OPTION 5: NON NETWORK OPTIONS

Non-network options do not address the risk associated with relay feeders.

Considering all technically feasible options, namely Options 1, 2, & 3, an analysis was carried out to select the technically feasible and credible options, summary of which is as follows:

Table 3-1: Summary of Options and their technical feasibility

Option #	Description of Option	Further sub-options	Whether technically feasible or not (Yes/No)	Whether selected for further evaluation (Yes/No)
1	Base Case – Do Nothing		Yes	Yes
2	Increase maintenance		Yes	Yes
3	Bulk relays replacement using digital substation technology	Carry out arrangement of panels in existing control building to accommodate new panels and systems	Yes	Yes
4	Piecemeal replacement of protection and control relays.		No	No
5	Non network option(s)		No	No

On the basis of above, options 1, 2, & 3 were considered for further evaluation.

3.3 EFFECTIVENESS OF OPTIONS IN ADDRESSING THE ISSUES AND RISKS

Presented below is a summary of how effective each of the three options are in addressing the risks and issues identified before:

Table 3-2: Summary of selected options and their efficacy in addressing identified issues

DESCRIPTION OF ISSUES	EFFECTIVENESS OF OPTIONS TO ADDRESS IDENTIFIED ISSUES		
	OPTION 1 Do Nothing	OPTION 2 Increase maintenance	OPTION 3 Bulk relays replacement using digital substation
Worsening of reliability of supply due to relays of older generation (electromechanical type), without spares	No	No	Yes
Degradation of reliability of supply due to failure of SR760 type relays failures	No	No	Yes
Worsening of security of supply due to obsolescence of relays and withdrawal of support from relay manufacturers	No	No	Yes
Deterioration of security of supply due to ageing supervisory cables	No	No	Yes

Degradation of security of supply due to aged and unmonitored duplicate protection schemes	No	Marginally	Yes
Prolonged fault clearance time due to protection relay failure - Longer fault clearance times leading to increased risk of damage to assets due to high energy let through (I^2t)	No	No	Yes
Safety risks to people due to failing and deteriorating protection relays	No	No	Yes

4. OPTION EVALUATION

From above, it is noted that:

- Option 1 (Do Nothing) does not address the risks and issues related to secondary system assets failure; it does not require any costs (CAPEX or OPEX)
- Option 2 only marginally addresses the issues but does not mitigate the risks; it requires increased OPEX by way of increased maintenance
- Option 3 addresses all issues and mitigates the identified risks associated with ageing and deteriorating secondary system assets with the transition in a safe manner including added benefits of digital smart substation.

In order to evaluate the options, economic analysis analysis were performed. Based on these, preferred option is selected.

4.1 ECONOMIC ANALYSIS

In line with the objective of the National Electricity Rules, JEN's investment decisions aim to maximise the present value of the net economic benefit to all those who produce, consume and transport electricity in the National Electricity Market.

To assess benefits against this objective, JEN has undertaken a probabilistic cost-benefit assessment of options that considers the likelihood and severity of critical network outages. The methodology assesses the expected impact of network outages or asset failures on supply delivery, and combines this with the value that customers place on their supply reliability and compares the result with the augmentation costs required to reduce the likelihood and/or impact of these supply outages or asset failures. The table below presents a summary of the cost-benefit assessment undertaken for this project.

4.1.1 SUMMARY OF CREDIBLE OPTIONS' EXPECTED COSTS & MARKET BENEFITS

The basic global parameters used such as discount rate, WACC, depreciation, assessment periods and other assumed constants are included in this analysis.

Table 4-1: Economic Analysis Results Summary

Description ($'000s, $2019)	Option 1	Option 2	Option 3
Total Expected costs	0	0	7,456
Total Expected market benefits	-	181	2,352
Net market benefits	-	181	-5,104
Option ranking	2	1	3

Option 3 is the recommended option as it mitigates safety risks and maintains reliability.

4.2 PROJECT TIMING

There is a separate need to replace 22 kV switchgear. In order to minimise disturbances to customers and avoid unnecessary outage, this project is to time in with the installation of new 22 kV switchboard in the existing building to house all new secondary system equipment.

The project target date is year 2024-2026.

5. RECOMMENDATION

The proposed Option 3 is recommended to be endorsed. This option consists of replacement of deteriorating protection and control equipment and the associated asset with modification to the existing control building at CS to house all new equipment, in the period 2024-2026, at an estimated cost of $7,456k (total project cost, real $2019).

This option is preferred based on following considerations:

- It recognises the critical role of protection relays in keeping the electricity network safe by timely clearance of network faults;
- It facilitates managing the health and safety risks to personnel, associated with deteriorating protection system assets, to As Low As Reasonably Practicable;
- It enables protecting the major assets such as power transformers; 66kV buses and 22kV buses etc from damage due to network faults;
- It ensures maintaining the current performance level on reliability of electricity supply to over 24,000 customers;
- It enables JEN to maintain supply of standard control services (**SCS**) from Coburg South (CS) zone substation as an efficient and knowledgeable operator should;
- It is technically prudent and addresses the risks identified, and it reduces the possibility that JEN would be found to have breached its general obligations associated with good asset management;
- It is in line with JEN approach of considering end-of-life replacement of assets with due consideration to useful life [9] and asset condition;
- It is in accordance with JEN's protection and control asset class strategy[10] and JEN's broader corporate objectives.

[9] JEN Network Asset Useful Lives Procedure (ELE PR 0012)

[10] Zone Substation Protection and Control Equipment Asset Class Strategy (JEN PL 0021)

Appendix A
Project Scope

A1. HIGH LEVEL SCOPE

Scope of Works for this business case consists of replacement of protection and control infrastructure and associated systems at CS zone substation and associated remote stations and includes the following:

High level summary of scope of works for this project is as follows:

At CS:

- Replace all existing protection & control relays at CS, except the 66kV line current differential protection relays.
- Install new AC distribution and fully duplicated 110V X & Y DC Supply System
- Install new RTU and communication equipment as well as the merging units for the implementation of IEC 61850 standard with process bus and smart substation features.
- Rearrange layout of the existing control building and control room area to house the new protection & control relays, DC Supply Systems etc.

At remote stations:

- No relay changes at remote ends except for testing purposes if required.

A2. PROJECT COST ESTIMATE

The estimated cost is $7,456k (total project cost, real $2019) including overheads of $1,110k ($2019).

Appendix B
Failure history of SPAJ and SR760 type feeder protection relays

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A3. FAILURE HISTORY OF SPAJ TYPE RELAYS

Date	Zone Substation	Description	Relay	Protection Description
14-Feb-06	AW	AW12	ABB SPAJ 140C	Feeder Protection
01-Jun-11	AW	AW7	ABB SPAJ 140C	Feeder Protection
06-Jun-12	AW	AW6	ABB SPAJ 140C	Feeder Protection
02-Jul-12	ST	ST No2 Cap Bank	ABB SPAJ 160C	Feeder Protection
23-Aug-12	**BD**	**BD10**	**ABB SPAJ 140C**	**Feeder Protection**
24-Aug-12	**BD**	**BD11**	**ABB SPAJ 140C**	**Feeder Protection**
27-Oct-12	**BD**	**BD06**	**ABB SPAJ 140C**	**Feeder Protection**
29-Mar-13	**BD**	**BD04**	**ABB SPAJ 140C**	**Feeder Protection**
28-Feb-13	AW	AW6	ABB SPAJ 140C	Feeder Protection

A4. FAILURE HISTORY OF SR760 TYPE RELAYS

Date	Zone Substation	Description	Relay	Protection Description
28-Nov-05	YTS	YTS8	GE SR760	Feeder Protection
28-Nov-05	YTS	YTS4	GE SR760	Feeder Protection
14-Dec-05	YTS	YTS3	GE SR760	Feeder Protection
18-Dec-05	YTS	YTS6	GE SR760	Feeder Protection
21-Dec-05	YTS	YTS2	GE SR760	Feeder Protection
08-Feb-06	YTS	YTS10	GE SR760	Feeder Protection
30-Mar-06	AW	AW14	GE SR760	Feeder Protection
01-Apr-06	SBY	SBY31	GE SR760	Feeder Protection
02-Apr-06	BD	BD No.2 Bus	GE SR760	No2 22kV Bus Protection
11-May-06	SBY	SBY11	GE SR760	Feeder Protection
27-Nov-06	AW	AW11	GE SR760	Feeder Protection
16-Mar-07	AW	AW14	GE SR760	Feeder Protection
17-May-07	AW	AW11	GE SR760	Feeder Protection
28-Jun-12	BY	BY11	GE SR760	Feeder Protection
29-Jun-12	BY	BY11	GE SR760	Feeder Protection
21-Aug-12	YTS	No.4 Tx	GE SR737	No.4 Trans HT OL
18-Jan-13	NS	NS13	GE SR760	Feeder Protection
18-Mar-13	BY	BY15	GE SR760	Feeder Protection
20-Jan-14	ST	ST34	GE SR760	Feeder Protection

Appendix C
Failure Information on SR760 Relays Collected from Relay Manufacturer (GE)

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C1. FAILURE INFORMATION ON SR760 RELAYS COLLECTED FROM RELAY MANUFACTURER (GE)

Information presented below was gathered from CSE Uniserve and from various other sources. Across Australia, GE relays are distributed by CSE Uniserve. They also provide technical support for all GE protection relays.

Accelerated Lifetime Testing Data:

GE has conducted extensive testing on the SR760 relay by performing Accelerated Lifetime Testing (**ALT**) which provides a tested assessment of lifetime expectation. ALT testing is a methodology to stress relays in a controlled way to provide indication of lifetime expectation.

In summary the following conclusions can be drawn from the ALT testing conducted:

- A minimum 13 year life can be expected based on a continuous 40 degree Celsius environment.
- A 36 year life can be expected based on a continuous 25 degree Celsius environment.
- It must be noted that the actual running temperature of internal components may be high as 20^{o}C above the ambient temperature.

    a. According to Bureau of Meteorology (**BOM**), average daily ambient temperature in Melbourne is 15^{o}C. Therefore, the operating temperature of a relay installation in Melbourne is around 35^{o}C (15^{o}C+20^{o}C=35^{o}C).

SR Series relay Power Supply Module:

- Due to the well know power supply issue associated with SR series relay, GE has made changes to the power supply module to improve the performance.
- Relays with firmware version 5.0 and above are shipped with the improved power supply module.
- Power supply module on the SR platform cannot be replaced. Entire relay will have to be replaced to get the improved power supply module.

Environmental Factors Affecting Relay Life:

Typically the power supply in any relay including the SR760 is the component that generally limits the overall life of the relay. The life of electrolytic capacitors used in power supplies is generally affected by two main factors:

a) Ambient operating temperature

b) Ripple current (DC power supply to relay)

The table below shows the effect of ambient temperature and ripple current on the life expectancy of electrolytic capacitor (and of the relay).

The power supply in digital relays are sensitive to high temperatures. Power supply failure is often attributed to electrolytic capacitor failure due to overheating.[6] This is a severe relay component failure because without the power supply, the relays will no longer function.

Life Expectancy

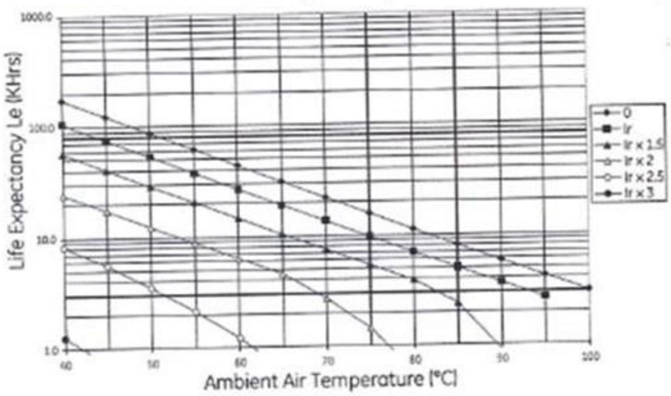

Figure 10[7]
Capacitor Life Expectancy vs Temperature and Ripple Current (ir).

Over time, capacitors lose their capacitance, a condition that is significantly accelerated when overheated.[6] As a rule of thumb, capacitor life will approximately halve with every 10°C increase in running temperature. As such, a capacitor rated for 5000 hours at 105°C will have an estimated application life of 25 years when running at 60°C, dropping to 12.5 years when running at 70°C. This is of particular concern for relays operated at high temperatures, as the actual running temperature of internal components may be as high as 20°C above the ambient temperature.

The graph [Figure 10] shows the negative effects of increasing ambient air temperature and increasing ripple current have on the life expectancy of a capacitor.

High operating temperatures can also effect the relay display. LCDs, and more specifically the liquid crystal material within the display chamber, can be permanently damaged in extreme temperatures. The result will be a loss of display resolution, discoloration, and display dead spots. (see Figure 8)

Appendix D
Network Risk Assessment

Business Case Summary JEN Asset Specific (Strategic) Context statement: Project Name: CS Relay Replacement Project Participants: Ken Lau Workshop Date: 27/9/18							Update Inserted / Deleted Cells	
			Before Implementing Strategy			Risk Treatment	After Implementing Strategy	
Identified Risk	Hazard Effect	Operational Risk Category	Consequence	Likelihood	Risk Rating	Control / Minimisation	Expected Likelihood	Expected Risk Rating
Failure of assets	Risk associated with the failure of protection relay having an impact on network reliability and JEN assets. Potential for an adverse impact to large number of customers 8060 per bus. Eg: Operation of 22kV bus distance protection for the failure of feeder protection during a fault on the feeder.	Operational (JEN)	Severe	Possible	Significant	Initiate a project to address deteriorating, failing and aged relays replacement at CS.	Rare	Moderate
Failure of assets	Risk associated with the possible loss of coordination due to electromechanical relays having reached end of their setting adjustment range (e.g. CDG type relays can not be further adjusted, leading to loss of calibration and required trip times). Impact on network reliability and JEN assets. Potential for an adverse impact to large number of customers (worst case scenario 9443 customers on No2 22KV Bus). Eg: Mal-operation of Tx HT OL prot mal-operation	Operational (JEN)	Severe	Unlikely	Moderate	Initiate a project to address deteriorating, failing and aged relays replacement at CS.	Rare	Moderate
Inadvertent impact on network reliability	Risk of inadvertent operation of protection relays during site works . Potential for an adverse impact to large number of customers (worst case scenario 9500 customers on Bus No.2).	Operational (JEN)	Severe	Possible	Significant	Establish process and rearrange layout to replace the protection and control equipments in an efficient and safe method.	Rare	Moderate
Risk associated with workplace H&S in case of any refurbishment or redevelopment works at CS	Risk of associated exposure to hazardous substances No possibility of any modifications to existing schemes in the control building, due to (a) inability to work on panels containing asbestos, and (b) very limited space and crowding in the existing building	Health, Safety & Environment (JEN)	Severe	Possible	Significant	Establish process and rearrange layout to replace the protection and control equipments in an efficient and safe method.	Rare	Moderate