# Jemena Electricity Networks (Vic) Ltd

## Mitigate Risk Associated with Protection Relays at Braybrook (BY) Zone Substation

2025 Business Case

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**Owning Functional Area**

| | |
|---|---|
| Business Function Owner: | Asset Strategy Electrical |

# 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 Jemena 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 Jemena 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 Braybrook (BY) zone substation to more than 10,000 customers including several major HV customers.
- This project proposes mitigation of risks associated with deteriorating 22 kV feeder protection, 22 kV bus protection relays and transformer protection relay at BY.
- The project is planned to be completed in 2021, at an estimated cost of $1,558k (total project cost, real $2019).

## 1.1 BUSINESS NEED

This business case relates to mitigation of risks associated with deteriorating protection relays at the Braybrook (BY) zone substation.

This project is necessary to:

- Maintain the performance of the protection asset class in accordance with accepted practices world-wide and Jemena'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 to As Low As Reasonably Practicable (ALARP) in line with Jemena Group Risk Management Manual (JAA MA 0050);
- Mitigate risk of asset damage; and
- Maintain reliability of electricity supply to 10,000 customers being served from BY zone substation
- The project is planned to be completed in 2021, at an estimated cost of $1,558k (total project cost, real $2019).

## 1.2 RECOMMENDATION

The proposed investment Option 3 is recommended to be endorsed. This option consists of replacement of deteriorating protection equipment at BY, in the year 2021, at an estimated cost of $1,558k (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 ALARP requirements;
- It enables protecting the assets such as distribution feeders, 22 kV busbar and 66/22 kV power transformers at BY from damage due to network faults;

- It ensures maintaining the reliability of electricity supply to 10,000 customers;
- It enables Jemena to maintain supply of standard control services (**SCS**) from Braybrook (BY) zone substation;
- It is technically prudent and addresses the risks identified above, 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 Secondary Plant Asset Class Strategy[2] and JEN's broader corporate objectives; and;
- It maximises the positive net benefit across the options considered, and represents the economically efficient option.

## 1.3 REGULATORY CONSIDERATIONS

There are no specific legal obligations that the protection infrastructure at BY 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 9A – Aug 2018), 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;*

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

2 JEM AM Electricity Secondary Plant Asset Class Strategy (ELE AM PL 0062)

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

d. *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 $1,558k (total project cost, real $2019) and requires Jemena Leadership Team – Executive General Managers (Band C) approval under the SGSPAA DFA Manual, Annex 3.

This project is included in the approved budget for CY21 and is required to be commissioned by 2021.

The business case is prepared in relation to regulatory submission for the period 2021-2025.

**Table 1-1: Project Budget Information**

| Budget Value | Total ($'000s, $2019) |
|---|---|
| CAPEX Budget | 1,350 |
| Overheads | 208 |
| **Total Budget Value** | **1,558** |

# 2. BACKGROUND

## 2.1 BUSINESS AND SOCIO ECONOMIC CONTEXT

Braybrook (BY) is a two transformer station, operating at 66/22 kV with two 22 kV buses. It supplies five 22 kV feeders, which all emanate from the No.1 22 kV bus (currently, the second bus has no feeders connected).

BY is located in Maidstone and is considered a critical substation, supplying approximately 10,000 urban customers and several major HV customers via these five feeders.

Each feeder is protected by a feeder management relay (located at BY). These relays enable JEN to comply with NER S5.1.9 (identified above), providing primary protection to JEN's assets and people (Note: backup protection is provided by 22 kV Bus Overcurrent protection). Their primary purpose is to detect electrical faults on the feeder and isolate the fault by tripping the 22 kV feeder circuit breaker (also located at BY).

These relays are of a modern microprocessor-based technology, and all of the same type, GE SR760. The relays are now 20 years old, having been installed when BY was commissioned in 1999.

Similarly, both No.1 and No.2 Transformers at BY are protected by duplicated transformer protection relays. Their primary purpose is to detect electrical faults on the transformer and isolate the fault by tripping the associated 66 kV and 22 kV circuit breakers at BY.

## 2.2 ASSET RISK (OR OPPORTUNITY) ANALYSIS

### 2.2.1 SHORT DESCRIPTION OF THE AFFECTED JEMENA ASSETS

There are two existing issues associates with the protection relays at BY:

1. The ongoing failure history and associated risks with the GE SR series relays.
2. An inherent legacy design flaw with the Transformer Protection relays.

These two issues and their associated risks are discussed below.

### 2.2.2 ONGOING RELAY FAILURES

**The issue with the GE SR series relays.**

The GE SR series (SR760 and SR745) relays have been used on the JEN network to protect feeders and transformers since 1999. The older GE SR series relays have a history of failure due to faulty power supply modules and input/output modules (I/O modules). The failure of the power supply module is caused by the age-related breakdown of the electronic components within these modules, in particular the capacitors. Since 2005, a total of 21 of the GE SR series relays have failed across JEN, including three at BY Zone Substation.

This failure mode will result in the relay not performing its primary purpose if required to do so (i.e. isolating the feeder it is protecting when the feeder suffers a fault). In this situation, the backup protection will be required to clear the fault. In the case of a feeder fault, the zone substation's bus over-current protection scheme will operate as the backup protection, isolating the whole bus to clear the feeder fault.

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

- **Increased possibility of serious injury or fatality** - It take longer for backup protection to clear the fault, and as a consequence, the fault and fault current remains on the network for longer. Therefore, there is a greater possibility that assets carrying this higher fault current could cause serious injury or fatality to JEN personnel and the 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 will be damaged.
- **Increased customer outages** - The number of customers that will lose supply will increase because the backup protection has isolated a wider area of the network. In the case of a feeder fault, the backup protection will result in all the customers supplied by that bus losing supply – rather than just those customers supplied by the faulted feeder.

It is also important to note that if the backup protection should fail then the fault may remain on the system for an extended period of time (in the order of minutes), greatly increasing the possibility of equipment damage (e.g. Transformer, 22 kV Bus) and injury. Should this event occur, leading to injury, there is a reasonable possibility that JEN could be found to be in breach of its safety management obligations.

The likelihood of these events occurring is increased in the case of these feeder relays for two reasons:

- **Lack of remote monitoring** - These modes of failure cannot be monitored remotely. Therefore, any failure remains undetected until the relay is physically tested, typically through its routine maintenance regime (which occurs on an 8-year cycle), or it fails to operate when required.
- **Lack of redundancy in the primary protection system** - Feeder protection relays are not duplicated like the protection schemes used for the more critical assets in a zone substation (e.g. bus, transformer and 66 kV line protection schemes). As such, the single failure of the relay requires backup protection to operate.

There are approximately 69 GE SR series relays in service across the JEN Network. According to relay manufacturer, relays with firmware versions 5 and below are prone to this power supply module failure.

Because of the issue with this relay type, JEN has implemented a strategy[3] to replace them. This strategy seeks to balance the risks of failure with the cost of replacing these relays by targeting relays based upon:

- The age of the relays. According to manufacturer, the power supply module is likely to fail as the relay approaches its end of life;
- The criticality of the customers that may lose supply (e.g. Hospitals); and
- Alignment with other network projects.

**The GE SR series relays at BY**

BY is considered to be one of the highest risk zone substations with the GE relays because the:

- firmware version of the SR760 relays at BY is 4.02 (contains the problematic power supply module);
- the relays at BY are 20 years old (and will be over 20 years old by the end of the current regulatory period). Typically, we expect the life of relays of this technology (Digital) to be in the order of 20 years;

[3] JEM AM Electricity Secondary Plant Asset Class Strategy (ELE AM PL 0062)

- the relays at BY have already had three recent failures of the type discussed here, supporting this view that these relays are approaching their end-of-life; and
- 10,000 customers at BY are connected to a single bus, and therefore, a feeder fault isolated via backup protection will result in all 10,000 customers losing supply – rather than around 2,000 that would lose supply if the relay operated correctly.

**Manufacturer Reliability Data for GE SR series relays**

JEN has consulted with the relay manufacturer to determine the reliability of SR series relays (*refer to Appendix B*). Below is a summary of the reliability data:

- Based on extensive Accelerated Lifetime Testing, a minimum of 13 year life can be expected based on a continuous 40 degree Celsius environment;
- The operating temperature of a typical relay in Melbourne is around 35$^{o}$C (15$^{o}$C+20$^{o}$C=35$^{o}$C); and
- The life of electrolytic capacitors used in power supplies is generally affected by two main factors:
    - Ambient operating temperature; and
    - Ripple current (DC power supply to relay)

Graph on Appendix B shows the effect of ambient temperature and ripple current on the life of a relay.

### 2.2.3 AN INHERENT LEGACY DESIGN FLAW WITH THE TRANSFORMER PROTECTION RELAY

Braybrook (BY) is a legacy ZSS which was not designed to the current Secondary Design Standard (JEN ST 0600). As it stands, the No.1 Transformer 'X' and 'Y' protection schemes employed at BY is unconventional and consists of one relay providing protections for the 66 kV bus and the transformer. As a result CT contribution to the relays are summated outside the relay.

Recently a similar protection scheme at Coolaroo (COO) zone substation mal-operated for an out of zone fault. This incident impacted approximately 16,611 customers including a number of HV customers. All supply was fully restored within approximately 25 minutes.

Subsequent Incident Investigation identified the following factors have contributed to unwanted operation of Transformer protection scheme:

1. Saturation of 66 kV Current Transformers (CTs); and
2. Incorrect implementation of non-standard transformer protection scheme by external turnkey contractor instead of dedicated unit protection as per Jemena standard.

Refer to Incident Investigation Report - Loss of Supply to Coolaroo ZSS.

In order to prevent recurrence of such incidents, the transformer protection relays at BY needs to be replaced with a Three Winding Transformer Protection relays.

### 2.2.4 RISK ASSESSMENT

A Project Risk Assessment has been carried out following Jemena's Networks Projects Business Cases Risks Budgeting and Assessment Guidelines document JEN GU 2502. This risk assessment highlights the current issues at BY zone substation and the risks to JEN business emanating from these risks, as well as initiation of the proposed project capital expenditure as an action to mitigate these risks.

Refer Appendix E.

Protection failure or mal-operation 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's (**ESV's**) Morwell Terminal Station Incident Final Report summary excerpt reads[4]:

> *"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 JEM AM Electricity Secondary Plant Asset Class Strategy (ELE AM PL 0062).

This section describes the issues and related risks with regard to the current state of the protection relays under discussion at BY.

#### 2.2.4.1 Degradation of reliability of supply, risk of asset damage and health & safety risk due to failure of SR760 type feeder protection relays

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:

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

- **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.

As an example, on 28th February 2013, there was a fault on feeder AW6; the feeder protection relay failed to operate; the back-up bus protection operated to clear the fault. Consequently, supply to all feeders on the 22 kV no 2-3 bus was lost affecting 14,522 customers. **This equates to an S-factor impact of $1.1M**.

All feeder protection relays at BY are type SR760. This relay has failed on three occasions during last 6 years at BY site. Further, since 2005 there have been a total of 19 instances of failure of feeder protection relay type SR760 in JEN.

Refer to Appendix C for details of SR760 type relay failures in JEN.

#### 2.2.4.2 Loss of supply to BY ZSS due to mal-operation of No.1 Transformer protections for an out of zone fault

As it stands, the No.1 Transformer 'X' and 'Y' protection schemes employed at BY is unconventional and consists of one relay providing protections for the 66 kV bus and the transformer. As a result 66 kV CT contribution to the relays are summated outside the relay.

As a result a solid fault on the 66 kV network (66 kV bus, 66 kV line or Transformer) can cause the CTs to go into saturation causing the No.1 Transformer Protection to mal-operate for an out of zone (external) fault.

Mal-operation of the No.1 Transformer Protection at BY for a fault on the No.2 Transformer or BY-ES 66 kV Line will have the following consequence.

- **Loss of Supply BY ZSS** – Supply to BY zone substation will be completely lost impacting approximately 10,000 customers for 30-60 minutes.

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

Table 2-1: Summary of issues and consequences

| Issue | Consequence |
| --- | --- |
| Failure of feeder protection relay type SR760 | Reliability of supply of SCS impacted (Loss of supply to at least 10,000 customers). |
| Mal-operation of No.1 Transformer Protection relay | Reliability of supply of SCS impacted (Loss of supply to at least 10,000 customers). |
| Aged and deteriorating relays | Reliability 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 the above issues of deteriorating condition of relays infrastructure.

The project is planned in the year 2021 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 $310,000 per annum;
- age and condition of relays infrastructure has deteriorated to a point where Jemena's ability to deliver SCS may be impacted;
- this project will enable Jemena to keep the risks arising from deteriorated and ageing assets to below ALARP level

The optimal timing for the commencement of the project is 2021.

## 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 health and safety risks to personnel
- Mitigate risks associated with asset damage due to deteriorating condition of protection relay infrastructure at BY
- 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 3. 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 JEMENA STRATEGY AND PLANS

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

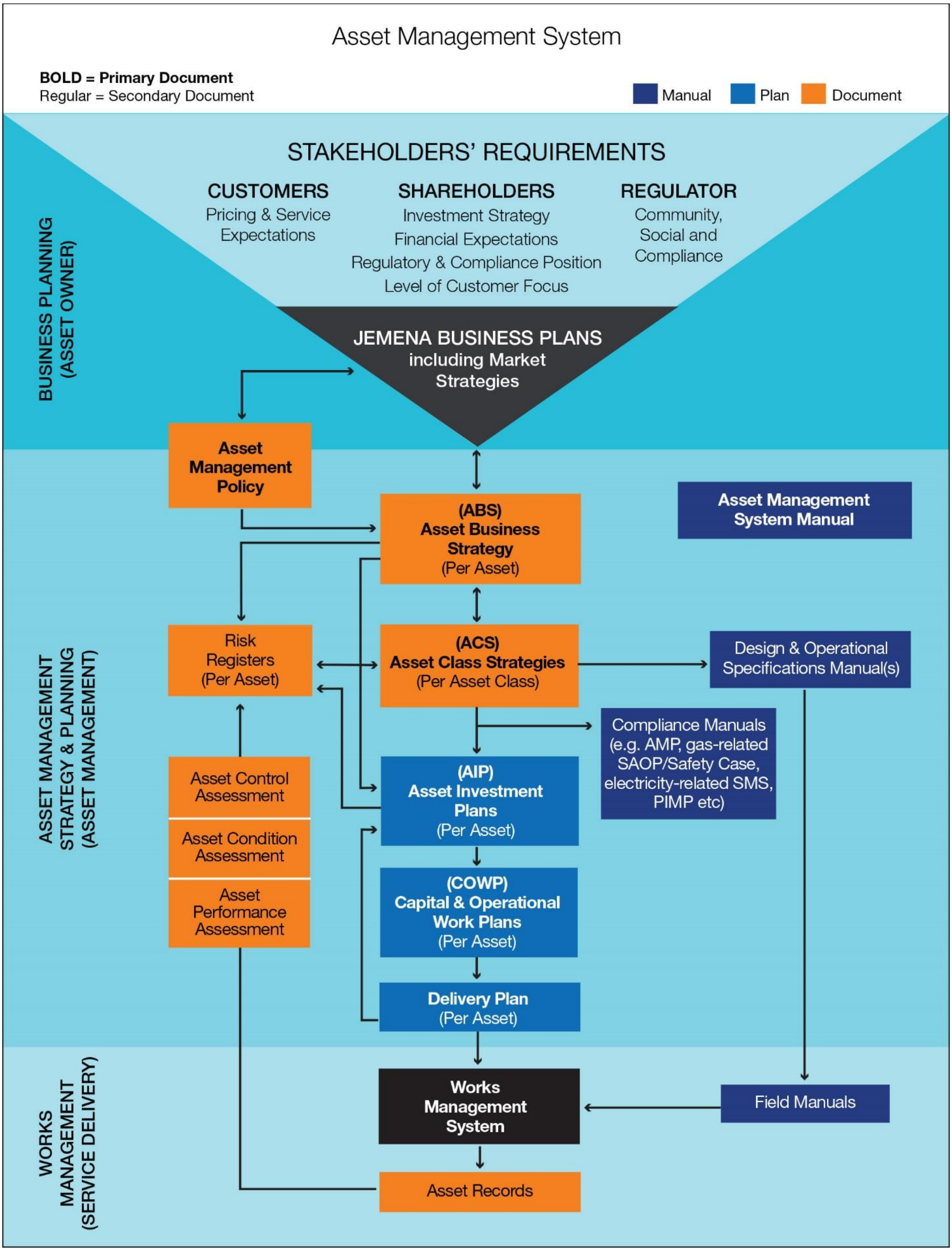
1. Efficiently and safely deliver affordable and reliable energy;
2. Make the customer experience easier and more valuable through digital and performance improvements; and
3. Modernise the grid to prepare for a connected future.

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

Figure 2–1 outlines the Jemena 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 Jemena Business Plan requirements.

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

**Figure 2–1: The Jemena 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 feasible options were considered to address the business need, problem or opportunity:

- Option 1: Do Nothing
- Option 2: Increase maintenance
- Option 3: Proactive relays replacement

These options are discussed in more detail below.

Non-network options are not considered given that the nature of the expenditure (i.e. replacement of protection & control infrastructure) is not compatible with a non-network solution.

### 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 – PLANNED AND PROACTIVE RELAY REPLACEMENT

Option 3 involves proactive and planned replacement of the protection and control infrastructure.

## 3.2 DEVELOPING CREDIBLE OPTIONS COSTS & BENEFITS

### 3.2.1 OPTION 1: DO NOTHING

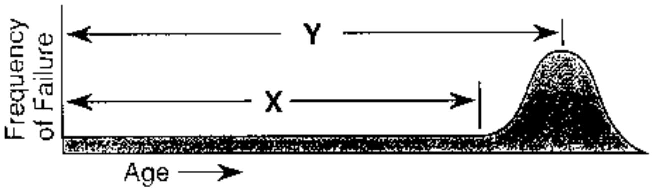
Option 1 represents Do Nothing scenario - that is, maintaining the status quo.

#### 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 BY Zone Substation. Under this option, relay equipment will undergo routine maintenance every eight years and will be replaced only when relay fault is detected.

Replacing relays upon failure poses risk of loss of electricity supply to customers, which is not acceptable (for example, supply to at least 10,000 customers could be lost, if a feeder protection relay did not operate during a feeder fault).

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:

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

The current condition of the protection and control relays has already resulted in several failures at the BY zone substation. In addition, relays of similar make and model as at BY 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
- Failure of feeder protection relays to operate during network fault and impact on STPIS
  - Failure of feeder 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)
- Mal-operation of No.1 Transformer protection relays and impact on STPIS
  - Mal-operation of No.1 Transformer protection relay for an out of zone fault on either the No.2 Transformer or BY-ES 66 kV line leads to loss of supply to all customers at BY (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%. Refer to Appendix C for Analysis of Relay Failure at BY.

### 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.

This option, however, has following consequences:

- Limitations of this option:
  - hidden failure of relay for maximum of 1 year period;
  - limited maintenance possibility
  - Increasing maintenance on relays will not address the issue with the Transformer Protection design concern at BY.
- 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.

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.

### 3.2.3 OPTION 3: PLANNED & PROACTIVE RELAY REPLACEMENT

#### 3.2.3.1 Scope, costs & timelines

Option 3 proposes the replacement of following protection and control relays at the BY zone substation.

1. BY11, 12, 13, 14 & 15 22 kV Feeder Protection;

2. No.1 & No.2 Transformer Protections;
3. No.1 & No.2 22 kV Bus Protections; and
4. Master Earth Fault Protection.

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

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

Further, planned replacement of the aged and deteriorating protection relays at BY also provides an opportunity to implement JEN secondary design standard, thus 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.

#### 3.2.3.2 Assumptions and forecasts

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

**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 | Planned and proactive relays replacement | | Yes | Yes |

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

# 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. This option will only identifies relays that have failed in the past 12 months and despite this additional effort and expenditure, there would be no guarantee that new problems would not occur with the relay.
- Option 3 addresses all issues and mitigates the identified risks associated with ageing and deteriorating relays.

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

## 4.1 ECONOMIC ANALYSIS

In line with the objective of the National Electricity Rules, Jemena'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, Jemena 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 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

Expected costs and expected market benefits associated with each of the credible options used in the ensuing economic evaluations are summarised in the following tables.

**Table 4-1: Economic Analysis Results Summary**

| Description ($'000, $2019) | Option 1 Do Nothing | Option 2 Increase maintenance | Option 3 Bulk replacement using conventional technology |
|---|---|---|---|
| **Total Expected costs** | 0 | 0 | 1,558 |
| **Total Expected market benefits** | Status Quo | 250 | 1520 |
| **Net market benefits** | N/A | 250 | -38 |
| **Option ranking** | 3 | 2 | 1 |

Based on the above economic analysis, Option 3 is the preferred option.

# 5. RECOMMENDATION

This business case proposes a total investment of $1,558k (total project cost, real $2019) and requires Jemena Leadership Team – Executive General Managers (Band C) approval under the SGSPAA DFA Manual, Annex 3.

It is recommended that Option 3 be adopted. This option consists of replacement of ageing and deteriorating protection relay infrastructure at the Braybrook (BY) Zone Substation with new modern equivalents.

This option would address all the condition issues identified in Section 2.2, which have a negative impact on safety, reliability and security of customer supply.

This option is considered prudent, has a positive net present value and is the preferred option, and will address all identified issues.

The total cost of this option is estimated to be $1,558k (total project cost, real $2019) and the project would commence in 2021.

# Appendix A
# Project Scope and Delivery Information

# A1. HIGH LEVEL SCOPE

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

a) Replace 22 kV Feeder protection, control & monitoring relays: quantity 5-off

b) Replace No 1 and No 2 22 kV bus ‘X’ High Impedance Bus protection relays: quantity 2-off

c) Replace No 1 and No 2 22 kV bus ‘Y’ Bus Overcurrent protection relays: quantity 2-off

d) Replace No 1 and No 2 Transformer protection relays: quantity 4-off

e) Replace Master Earth Fault (MEF) protection relay: quantity 1-off

# A2. PROJECT COST ESTIMATE

Estimated cost $1,558k (total project cost, real $2019) including overheads.

# Appendix B
# Information on SR series Relays Collected from Relay Manufacturer (GE)

# B1. INFORMATION ON SR SERIES RELAYS COLLECTED FROM RELAY MANUFACTURER (GE)

Information presented below were gathered from CSE Uniserve and from various other sources. Across Australia, GE relays are distributed by CSE Uniserve. They also provide technical support to all GE relays. They are JEN's point of contact for any issues we face with GE relays.

**Accelerated Lifetime Testing Data:**

GE has conducted extensive testing on the SR series 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.
  - According to Bureau of Meteorology (**BOM**), average daily ambient temperature in Melbourne is 15ºC. 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 acknowledged power supply issue associated with SR series relay, GE has changed the power supply module to improve the performance;
- Relays with firmware version 5.0 and above are shipped with the improved power supply module; and
- 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 SR series relay 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:

1. Ambient operating temperature; and
2. Ripple current (DC power supply to relay)

The table below shows the effect of ambient temperature and ripple current on the life expectancy of a 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.[5] This is a severe relay component failure because without the power supply, the relays will no longer function.

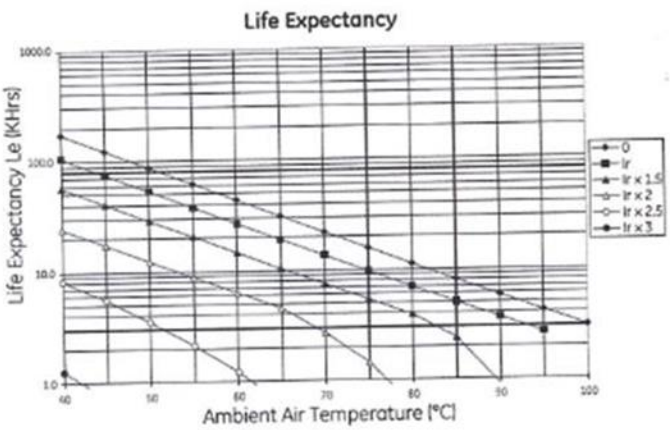



**Figure 10**[7]
*Capacitor Life Expectancy vs Temperature and Ripple Current (Ir).*

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 C
# Analysis of Relay Failure at BY

# C1. ANALYSIS OF RELAY FAILURE AT BY

The purpose of this section is to set out the analysis of relay failure risks. It focuses on:

- Analysis of historical failures
- Development of BY risk assumptions

**Failure Modes**

In order to develop a risk cost associated with a failure of any of the five feeder protection relay at BY, a likelihood of failure and associated consequence of failure has been developed.

**Failure Modes**

Likelihood of supply interruption to the 22 kV bus at BY due to the failure of feeder protection relay is defined by the following formula:

$$\mathrm{P}_{\mathrm{Event}} = \mathrm{P}_{Relay} * \mathrm{N}_{Feeder} * \sum \mathrm{N}_{Feeder\ Outages\ per\ annum\ at\ BY}$$

Where:

- $P_{Event}$ = Probability of supply interruption to the 22 kV bus at BY leading from the failure of feeder protection relay.
- $P_{Relay}$ = Probability of GE SR 760 feeder protection relay failure.
- $N_{Feeder}$ = Number of feeder at BY ZSS (5 in total).
- $N_{Feeder}$ Outages per annum at BY = Total number of feeder outages per annum.

**Likelihood of Relay Failure:**

The particular feeder protection relay used at BY is SR760 relay manufactured by General Electric (**GE**). There are five SR760 relays installed at BY out of a total population of 49 relays across JEN. A total of 20 GE SR series relays have failed across the JEN. The following table presents the list of failed GE SR series relays across the network.

**Table C1–1: List of failed GE SR series relays since 2005**

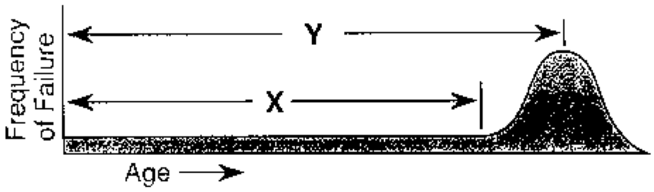
| Date | Year | Zone Substation | Description | Relay |
|---|---|---|---|---|
| 28-Nov-05 | 2005 | YTS | YTS8 | GE SR760 |
| 28-Nov-05 | 2005 | YTS | YTS4 | GE SR760 |
| 14-Dec-05 | 2005 | YTS | YTS3 | GE SR760 |
| 18-Dec-05 | 2005 | YTS | YTS6 | GE SR760 |

| Date | Year | Zone Substation | Description | Relay |
|---|---|---|---|---|
| 21-Dec-05 | 2005 | YTS | YTS2 | GE SR760 |
| 8-Feb-06 | 2006 | YTS | YTS10 | GE SR760 |
| 30-Mar-06 | 2006 | AW | AW14 | GE SR760 |
| 1-Apr-06 | 2006 | SBY | SBY31 | GE SR760 |
| 2-Apr-06 | 2006 | BD | BD No.2 Bus | GE SR760 |
| 11-May-06 | 2006 | SBY | SBY11 | GE SR760 |
| 11-Jul-06 | 2006 | NS | NS13 | GE SR760 |
| 1-Jan-06 | 2006 | NS | NS13 | GE SR760 |
| 27-Nov-06 | 2006 | AW | AW11 | GE SR760 |
| 16-Mar-07 | 2007 | AW | AW14 | GE SR760 |
| 17-May-07 | 2007 | AW | AW11 | GE SR760 |
| 28-Jun-12 | 2012 | **BY** | **BY11** | **GE SR760** |
| 21-Aug-12 | 2012 | YTS | No.4 Tx | GE SR737 |
| 18-Jan-13 | 2013 | NS | NS13 | GE SR760 |
| 18-Mar-13 | 2013 | **BY** | **BY15** | **GE SR760** |
| 20-Jan-14 | 2014 | ST | ST34 | GE SR760 |

These failure records indicate that 39% of the SR series relays have failed since 2005 at a rate of 6.5% per annum.

It must be noted that, the useful life of a relay cannot be predicted exactly. It is a window of time where it is expected that a particular relay type is likely to start to exhibits signs of irreversible deterioration in performance. This window of time is taken as ±10% of the nominated useful life (20 years for SR760 relay). The useful life can obviously change as more information presents itself. It is reasonable to assume a useful life and a wear out characteristic based upon the Weibull distribution (see below).

**Figure C1–1: Relay Population Failure Characteristic**




In summary, for a given population of relays of the same age and similar design and construction, the likelihood of failure during the useful life period X is relatively low and assumed to be constant (say less than 1%). At an age just beyond the useful life expectancy, the likelihood of failure and therefore the frequency of failure will also increase as a result of aged related deterioration. As the population continues to age, the likelihood of failure is assumed to also increase resulting in a further rise in the frequency of failure. At an age Y the frequency of failure begins to reduce due to the reduction in the remaining population (and not due to a decrease in the likelihood of failure).

**Likelihood of Feeder Fault:**

Table below lists the likelihood of a feeder fault at BY zone substation. This is inclusive of both transient and permanent faults. Transient faults are fault caused by lightening or a tree branch coming into contact with the bare conductor during high winds. Permanent faults are generally caused by asset failure (e.g. insulator failure) or by human (e.g. car into a pole).

**Table C1–2: Feeder fault per year**

| Feeder | Number of Customers | Sustained Feeder outage | Momentary Feeder Outage | Total Feeder Outages per annum at BY |
|---|---|---|---|---|
| BY11 | 4,031 | 0.60 | 0.60 | 1.20 |
| BY12 | 1,271 | 0.60 | 0.40 | 1.00 |
| BY13 | 746 | 0.40 | 0.80 | 1.20 |
| BY14 | 2,895 | 0.60 | 0.40 | 1.00 |
| BY15 | 997 | 1.80 | 0.80 | 2.60 |
| Total | 9,940 | 4.0 | 3.0 | 7.0 |

Therefore average number of feeder fault at BY is 1.4 faults/annum

$$\mathrm{P}_{\mathrm{Event}} = 6.5\% * 5 * 1.4 = 45.5\%$$

Therefore the likelihood of supply interruption to BY ZSS due to the failure of a feeder protection to isolate a feeder fault is estimated to be 45.5%.

# Appendix D
# Network Risk Assessment Summary

# D1. NETWORK RISK ASSESSMENT SUMMARY

Click here for INSTRUCTIONS

Business Case Summary JEN Asset Specific (Strategic)
Context statement: Project Name: Mitigate Risk Associated with Protection Relays at Braybrook (BY) Zone Substation
Participants: Kopee Vaikundan
Workshop Date: 27/09/18

Update Inserted / Deleted Cells

| Identified Risk | Hazard Effect | Operational Risk Category | Before Implementing Strategy | | | Risk Treatment | After Implementing Strategy | |
|---|---|---|---|---|---|---|---|---|
| | | | Consequence | Likelihood | Risk Rating | Control / Minimisation | Expected Likelihood | Expected Risk Rating |
| Loss of supply to BY ZSS | Risk associated with the failure of protection relay having an impact on network reliability and JEN assets.<br><br>Potential for an adverse impact to large number of customers (worst case scenario 10,000 customers on No1 22kV Bus).<br><br>Eg: Operation of 22kV bus 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 BY. | Rare | Moderate |
| Loss of supply to BY ZSS | Risk associated with the mal-operation of No.1 Transformer protection relay having an impact on network reliability and JEN assets.<br><br>Potential for an adverse impact to large number of customers (worst case scenario 10,000 customers).<br><br>Eg: Mal-opertion of No.1 Transformer protection for an out of zone fault in No.2 transformer. | Operational (JEN) | Severe | Possible | Significant | Initiate a project to address the design flaw. | Rare | Moderate |