STRATEGY

ELECTRICITY SECONDARY PLANT ASSET CLASS STRATEGY

ELE AM PL 0062

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INTERNAL

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DOCUMENT HISTORY

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2.0	30/08/2018		Updates and addition to address Information, Risk, Spares and Criticality definition
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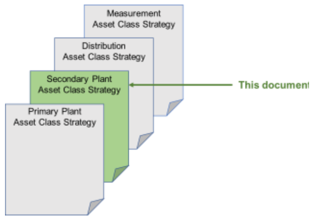
EXECUTIVE SUMMARY



There are four ACS documents incorporated into JEN's Asset Management System

Jemena Electricity Networks (JEN) in Victoria has an Asset Management System (AMS) that contains a set of four Asset Class Strategy (ACS) documents. The ACSs are hierarchically governed by the Asset Business Strategy (ABS) of the AMS.

This ACS document pertains to Electricity Secondary Plant, a term that denotes a range of equipment that is used in zone substations. Electricity Secondary Plant encompasses all the necessary on site equipment and systems to protect and control Electricity Primary Plant (load carrying equipment such as transformers, circuit breakers and bus switches).

The first three sections of this ACS are generic to all the ACS documents. The fourth section is where the Electricity Secondary Plant is unpacked and divided into sub-asset classes

- Protection & control equipment
- DC supply system
- Communications cabling
- Multiplexers
- Radio & cellular
- Remote terminal units
- Communication network devices
- GPS clocks

Substation & Distribution Automation

Each sub-asset class is described and discussed in terms of its associated risk, performance, life cycle management and budgetary forecasts.

The financial forecasts form the key findings of this ACS. This capital expenditure (CAPEX) and operational expenditure (OPEX) data informs the business and is shared, in commercial confidence, with the Australian Energy Regulator (AER) as part of the Electricity Distribution Price Review (EDPR) determination.

CAPEX and OPEX forecasts

CAPEX $000	2021	2022	2023	2024	2025	2026
Protection & control	$4,232	$3,879	$4,065	$3,668	$4,574	$6,549
DC supply system	$289	$526	$471	$605	$659	$295
Substation Distribution & Automation [1]	$48	$110	$61	$345	$330	$363
Totals	**$4,569**	**$4,515**	**$4,597**	**$4,618**	**$5,563**	**$7,207**

[1] Majority of Substation Distribution & Automation project are not standalone projects and are summed into larger projects. To avoid 'double counting', only the standalone project costs are captured in this table.

OPEX $000	2021	2022	2023	2024	2025	2026
Protection & control	$160	$163	$168	$174	$178	$182
DC supply system	$74	$76	$78	$80	$82	$82
Substation Distribution & Automation	$878	$486	$492	$600	$508	$414
Totals	**$1,112**	**$725**	**$738**	**$854**	**$768**	**$678**

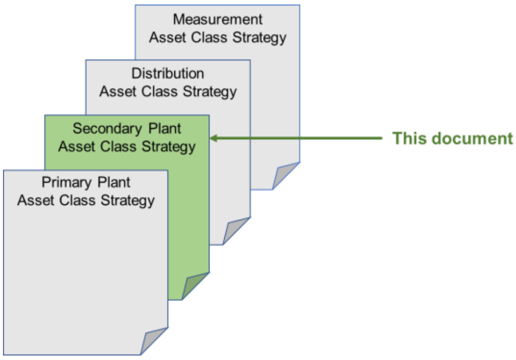
1 INTRODUCTION

This Asset Class Strategy (ACS) covers the Jemena Electricity Networks (JEN) secondary plant asset class and outlines the methods employed, analysis undertaken and actions to be taken to optimally manage the assets. The document serves as both an internal document to prescribe the management of the secondary plant asset class but also to support expenditure proposals as part of JEN's electricity distribution price reset (EDPR) submission process.

Within JEN's Investment Framework and Asset Business Strategy (ABS), asset life cycles are considered in terms of creation (acquisition), maintenance or replacement, as applicable, and disposal. Investment recommendations are made by analysing asset condition and age profiling.

There are four Asset Class Strategy (ACS) documents. Each ACS outlines performance measures and objectives which are used to attain key performance targets. This gives visibility to the performance of the asset and, in turn, informs investment decision making.

Figure 1 – ACS documents hierarchy



The secondary plant assets in this ACS are categorised into the following sub-asset classes located in the following sections of this document:

- 4.1 Protection & Control
- 4.2 DC Supply Systems
- 4.3 Communications Cabling
- 4.4 Multiplexer Systems
- 4.5 iNet Radio & Cellular
- 4.6 Remote Terminal Units
- 4.7 Communication Network Devices
- 4.8 GPS Clocks

1.1 PURPOSE

The purpose of the ACS Electricity Secondary Plant is to document the practical approach that supports the delivery of asset management objectives set out in the JEN's ABS.

This ACS is based on key information about each sub-asset (including risk, performance, life cycle management, capital expenditure and operational expenditure). Based on this information, this ACS contributes to short, medium and long-term planning.

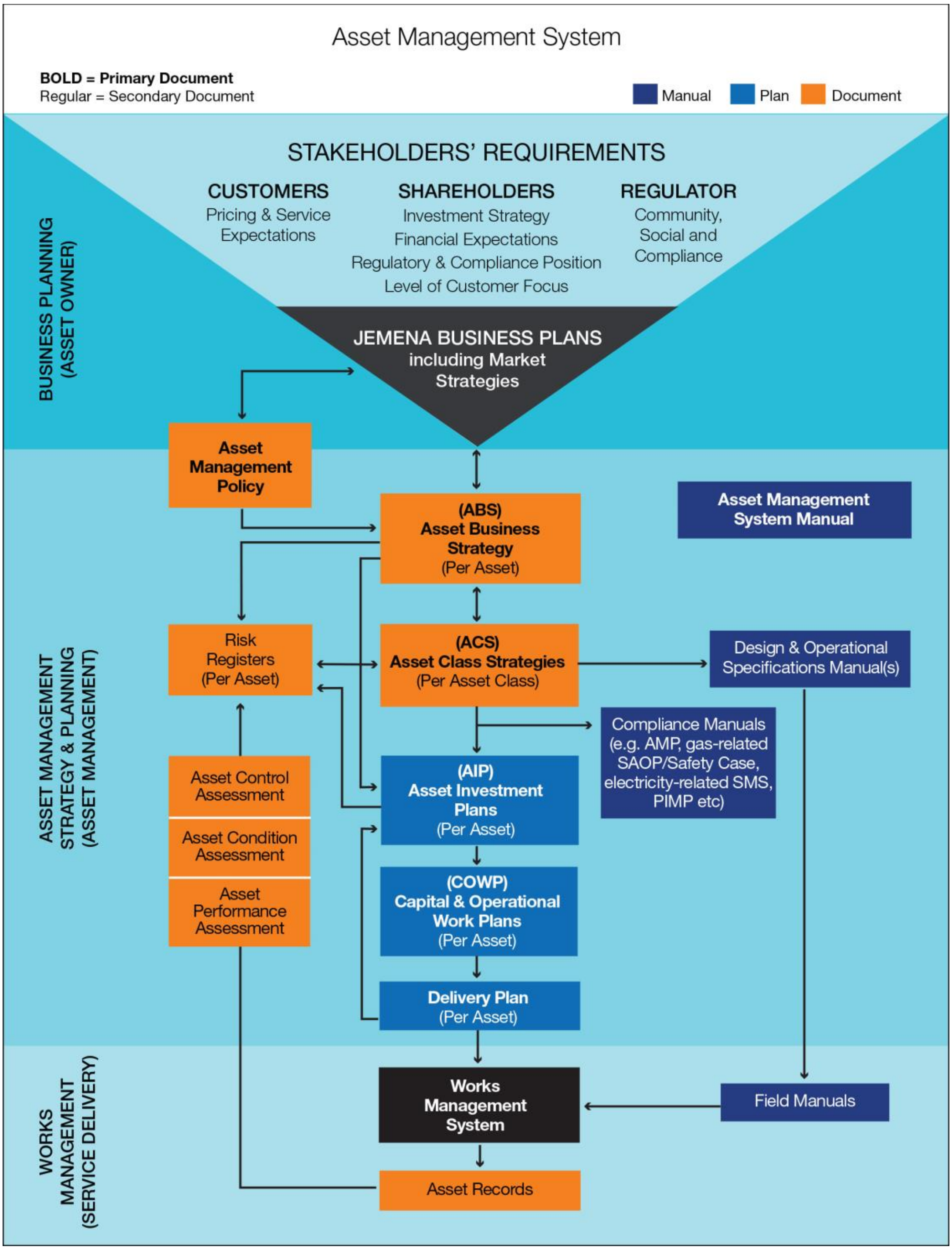
This secondary plant ACS addresses:

- Secondary plant asset management practices alignment with the ABS;
- Sub-asset risk causes and consequences;
- Sub-asset performance against objectives, drivers, and service levels;
- Sub-asset class specifications and life cycle management of electricity secondary plant assets in-service;
- Asset condition, along with relative cost considerations, are the primary drivers in making asset maintenance versus asset replacement decisions; and
- Risk weighted decision-making and financial estimates used to inform Operating Expenditure (OPEX) and Capital Expenditure (CAPEX) planning.

1.2 ASSET MANAGFEMENT SYSTEM

The ACS documents reside in JEN's Asset Management System (AMS) and creates a line of sight between the Business Plan and JEN's ABS through to the associated Asset Management Plan (AMP). Each ACS ensures that the performance, risks and cost of each asset class are analysed and optimum plans developed to align with the Business Plan.

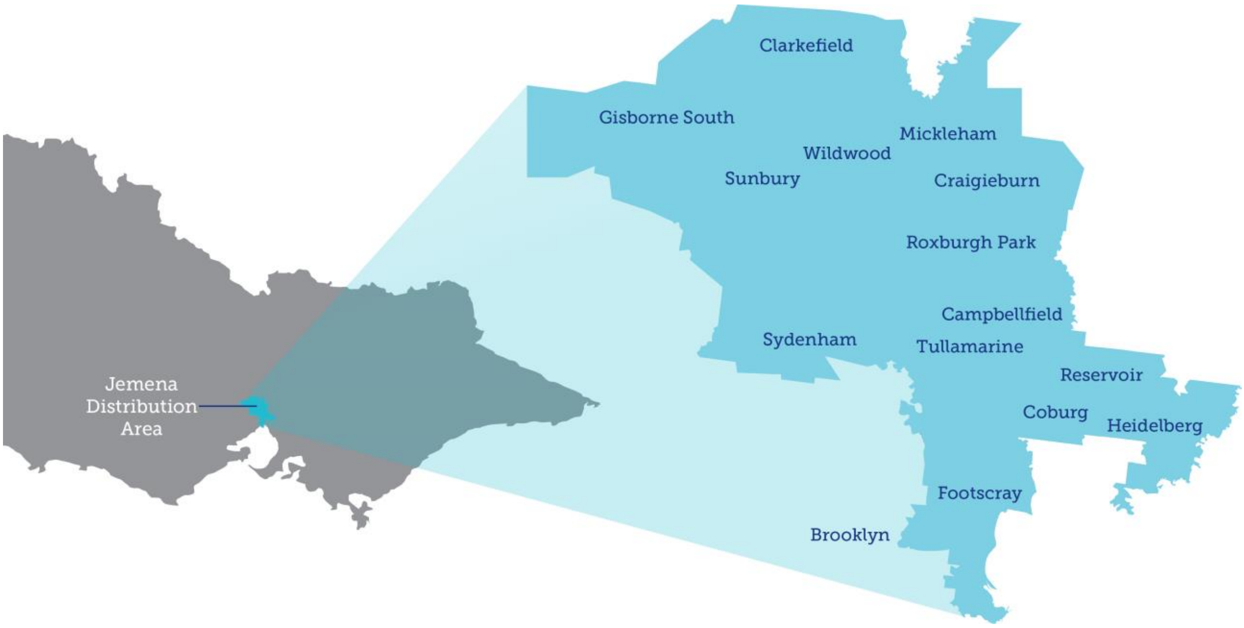
Figure 2 – JEN's Asset Management System



1.3 DESCRIPTION OF ASSETS COVERED

With particular sub-assets, such as relays or DC supply systems, there are risks of high consequence-of-failure impacting HSE objectives and/or supply reliability. Back-up protection is intrinsically designed into zone substation secondary systems. When a fault occurs and the initial protection fails to function, the back-up protection scheme is designed to activate. The extent of that outage would, however, be greater because the back-up scheme is upstream of the initial scheme.

Figure 3 – JEN's geographical footprint



There are a large number of secondary plant assets with varying degrees of severity if there is a failure.

JEN operates 26 zone substations and 4 customer substations equipped with:

- 1,766 Protection and Control Devices ranging in age from 0 to 60 years;
- 78 Battery Banks and Battery Chargers for DC Supply Systems;
- 21 GPS Clocks ranging in age from 1 to 18 years;
- 56 Communications Network Devices ranging in age from 1 to 12 years;
- 30 RTUs ranging in age from 1 to 26 years;
- 83 Multiplexers ranging in age from 2 to 18 years;
- 263 Radio Transceivers and Cellular Modems ranging in age from 1 to 18 years; and
- 348 km of Communications Cable ranging in age from 3 to 75 years.

1.4 GOVERNANCE

1.4.1 APPROVAL AND COMMUNICATIONS

Asset Class Strategy documentation is updated annually by the Asset Engineering Manager for approval by General Manager Asset Management Electricity Distribution.

The asset class strategy is reviewed annually to ensure alignment with the Asset Management objectives and to account for any additional asset performance and risk information.

1.4.2 RESPONSIBILITIES

Key stakeholder personnel are:

Job Title	Responsibility
GM Asset Management Electricity Distribution	Approval
Asset Engineering Manager	Document owner
Senior Protection & Control Engineer	Protection & Control equipment
Substation & Distribution Automation Engineer	GPS Clocks, Communication Network Devices, RTU, Multiplexers, iNet Radio & 3G Services and Communication cables
Senior Protection & DC Systems Engineer	DC Supply Systems

2 STRATEGIC DRIVERS

The ABS (2019, p16) states the asset management strategic drivers are:

- Market and competitive position, future growth, demand and customer connections;
- Customer and community expectations (service levels);
- Stakeholder expectations;
- Regulation and legislative environment;
- Asset management capabilities (processes, systems, resources, knowledge);
- Technology; and
- Other drivers relevant for the asset such as climate change.

Combined, these strategic asset management drivers ensure JEN optimises the condition, performance and associated costs over the life of each asset.

Figure 4 – Jemena's high level strategic goals informs the ABS

2.1 GROWTH

The coming 20 year period for the electricity network holds significant uncertainty. Customer behaviours are changing with the advent of new technologies which have the potential to reduce the need for the network as a source of supply, while at the same time, the demand for supply quality and growth in customer connections continue to rise. These two forces act against one another, JEN's expected position entering the next regulatory reset period is that demand growth, network wide, will continue at a similar rate as the last regulatory reset period. That stated, there are areas within the network where maximum demand growth is forecast well beyond the network average level while other parts of the network are forecast to experience reductions in maximum demand as a result, for example, of manufacturing closures. Analysis is ongoing and JEN's ABS will evolve as new insights emerge. JEN's ABS contains the ten year forecast which the business is working to. JEN is actively monitoring several dynamics which impact this forecast. Refer to the JEN ABS for further details.

2.2 STAKEHOLDERS

2.2.1 **Customers**

Decision making on behalf of customers involves trade-offs. For example, our customers consistently tell us they value a safe, reliable and responsive supply of electricity. But they also tell us that rising energy prices have become a concern. These priorities are mixed, as higher service levels involve higher costs. It is a 'trilemma'.

JEN's ABS states,

> *'The community expects environmental responsibility; a safe and reliable level of service; a responsive service; public amenity; equitable levels of service available to all consumers; and affordable pricing.'* (2019, p51)

2.2.2 SHAREHOLDERS

Asset procurement and operation must support the network's ability to produce and sustain profitability for shareholders.

JEN's ABS states,

> *'Our asset management decisions need to take into account the certainty our shareholders have about recovering their significant up-front investment in the asset*.' (2019, p21).

2.2.3 INTERNAL

Each ACS relies upon the contributions of several areas of the business. Stakeholders have business and operational insights that contribute to the effectiveness of the asset management. There are also reporting requirements back into the business. Section 1.2 *Asset Management System* maps stakeholder requirements.

2.3 REGULATORY AND LEGISLATIVE

JEN meets legal, licence and regulatory obligations so as to comply with the National Electricity Rules (NER) mandated by the Australian Energy Market Commission (AEMC) together with other rules, codes and guidelines set forth by:

- Australian Energy Regulator (AER);
- Energy Safe Victoria (ESV); and
- Essential Services Commission (ESC).

The JEN ABS describes how the business complies with the requirements of each of these stakeholders in order to retain its distribution licence, adhere to the NER and meet safety obligations. There are perennial compliance, analysis and reporting requirements that JEN is required to perform with regard to asset management. For example, JEN provides an annual RIN to the AER for all zone substation and distribution assets so as to account for the state of the network in terms of asset cost, age, reliability and cost of operating the network.

3 ASSET OBJECTIVES

JEN's objectives

> *…provide the essential link between the Jemena Business Plan's strategic objectives and the JEN asset management plan that describe how the objectives are going to be achieved. The asset objectives transform the required outcomes (product or service) to be provided by JEN, into activities typically described in the JEN asset management plan. This in-turn provides the line of sight for asset management activities* (ABS 2019, p50).

Asset Class Strategy objectives are:

- The practice of a Health, Safety and Environmental (HSE) culture that proactively seeks to control HSE risks.
- Optimise asset availability. Each asset failure is recorded and evaluated. Using standard risk assessment guidelines, an estimate of equipment failure rates are made. Annual probabilistic failure rates can be derived. A documented inspection, condition monitoring, maintenance and replacement strategy is included in this document for all assets to minimise the probability of failure and contains deterioration in service levels.
- Optimise asset life cycle. Defer asset replacement expenditure by use of condition monitoring. Where practical, conduct routine inspections, that can increase in frequency, as the asset approaches its statistical end of life. The aim is to defer capital expenditure whilst controlling the risk of failure and, thus, to contain deterioration in service levels.
- Standardisation and application of established design principles minimises the design and life cycle costs of assets installed. For instance, standardisation of specifications for purchasing of secondary plant assets together with the construction of zone substation physical assets and facilities, achieves efficiencies. These co-ordinated and integrated designs are particularly focused on attributes of robust long life, security, reliability and cost effectiveness.

A table assigning KPI's to the above objectives and aligning them to the ABS is located at Appendix B.

Figure 5 - Five key success measures and objectives

4 SUB-ASSET CLASS STRATEGIES

4.1 PROTECTION & CONTROL

4.1.1 INTRODUCTION

The protection and control equipment (also variously known as Relays or Intelligent Electronic Devices) are designed and configured to detect the presence of network faults and/or other abnormal operating conditions and to automatically initiate action to either isolate the faulted network by the opening of appropriate circuit breakers or to correct the abnormal operating condition by initiating some pre-defined control sequence. Protection and control equipment is installed within zone substations and continuously monitors the output of transducers, sensors and instrument transformers (e.g. current transformers and voltage transformers).

In 2015 JEN commenced incremental implementation of IEC 61850 (partial station bus at BMS and TMA). IEC 61850 (full station bus &) is presently being rolled out at PTN. Completion is expected in 2020.

The type of protection and control equipment applied varies from simple time delayed over-current relays to more complex differential and distance protection schemes depending upon the primary asset being protected or controlled, the type of fault to be detected and other considerations such as speed of fault isolation.

It is critical that every network fault be detected and automatically isolated by opening of high voltage circuit breakers. This is achieved by correct operation of protection relays. It is a regulatory requirement (Clause C, NER Version 63, Section 5.1.9) , as well as inherent to standard design practice in JEN and other utilities, that protection relay schemes are either duplicated or backed up by another relay. This design philosophy reduces the risk of a network fault not being isolated, but often the total time taken to isolate by backup protection is longer and a greater number of customers are interrupted in isolating the fault. For example, consider a typical feeder protection relay backed up by a bus overcurrent protection relay, failure of the feeder protection relay to detect and isolate a feeder fault will result in the bus overcurrent relay operating and tripping off supply to the entire bus, impacting a larger number of customers than if the feeder relay had been effective.

In cases where both the initial relay scheme and backup scheme fail, then the fault is unlikely to be isolated. Failure of two devices is generally not catered for in design, and the potential for such a situation is mitigated through routine maintenance and monitoring. It is in breach of the Electricity Safety Management Regulations (Part 10, Division 2 of the *Electricity Safety Act 1998*) if substation plant is in-service without protection.

When new protection and control equipment is installed or existing assets are replaced, they are designed and installed in accordance with zone substation Secondary Design Standard (JEN ST 0600) and Protection and Control Settings Manual (ELE AM MA 0003). These standards produce a common proven platform for design, installation and testing, minimising the scope for errors.

This ACS does not cover protection and control equipment installed at seven AusNet Services terminal stations that are used to protect JEN sub-transmission lines. This equipment is owned by AusNet Services. Replacement of sub-transmission line protection equipment installed at JEN owned zone substations may also require a like replacement at the remote end by either:

1. AusNet Services (in the case of a terminal station line exit); or
2. Another distribution business' zone substation (e.g. CitiPower & Powercor)

This sub-asset class does not cover any voice frequency (VF) or other legacy analogue remote trip equipment used for protection signalling between stations. This equipment is maintained and replaced according to the Communication Cabling sub-asset section elsewhere in this ACS. All new digital remote trip schemes will be implemented over JEN owned fibre optic communication channels via multi-function digital line current differential protection relays.

This ACS does not cover protection and control schemes that ship with zone substation transformers such as top oil and winding temperature monitoring, gas protection and cooling control schemes. This equipment is considered to be part of the Electricity Primary Plant ACS.

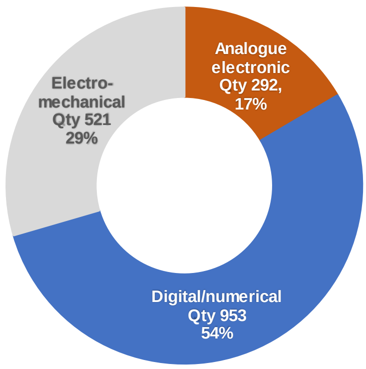
Zone substation protection and control equipment can be classified by protection and control functionality, namely:

- Protection of feeders, transformers, capacitors, busses and lines; or
- Control of circuit breakers, transformer tap-changers for voltage regulation and of capacitor bank switching.

Protection and control equipment have evolved and changed significantly over the past 70 years and can be categorised thus:

- Electro-mechanical (1950-1970 relay generation);
- Analogue electronic (1970-1985); and
- Digital/numeric (1985-Present).

Figure 6: JEN's relay population by technology type



Electro-mechanical relays

Electro-mechanical relays represent a mature and reliable technology that has been used extensively for many years in the electricity supply industry both locally and overseas. These relays use electro-mechanical components to provide the operating characteristic of the relay and are typically single function/single phase devices. They include attracted armature, solenoid, induction disk, balanced beam and induction cup designs. In some designs, discrete electronic components may also be used to filter and/or rectify the measured AC quantities (voltage and/or current). Electro-mechanical relays do not require any auxiliary power supply; rather they are self-powered devices drawing their operating energy directly from the measured voltage and/or current. The majority of relays of this type used in the JEN network are induction disc relays and are used for inverse time over-current protection applications. Examples of this relay type include CDG11, ICM21, RI, PBO, RVL, CAG and VAT. Given their reliance on moving parts, electro-mechanical relays require regular preventative maintenance performed by experienced personnel. Some specific electro-mechanical relays such as the CDG range of inverse time overcurrent relays are still being manufactured today, however they are no longer being purchased by JEN nor are they widely used within the electricity supply industry. This relay technology has no cost advantage (cost may be higher than the numerical equivalent) and digital relays have superior functional capability.

Analogue electronic relays

Analogue electronic relays are solid state or static relays, that is, there is no armature or other moving element associated with measurement and decision making process of the device. The response of the relay is developed by electronic component designs without mechanical motion. The measured AC quantities (voltage and/or current) are converted into much lower voltages but nonetheless similar (replica) analogue signals which are then combined or compared directly to reference values using level detectors to produce the desired output. Analogue electronic relays require an auxiliary DC power supply to energise their sensitive electronics and are therefore connected to the DC supply system of the zone substation. The first generation in this trend utilised the transistor in discrete electronic component designs. The second generation introduced the Integrated Circuit (IC) and operational amplifiers. Many of these semi-conductor components used, particularly in the early relays, are no longer produced. Analogue relays where first introduced into the network during the period 1970-1990 and offered improved sensitivity, speed of operation and repeatability over that of the electro-mechanical relays. They inherently require less maintenance and usually come with multi-function capabilities and within a much smaller package. As this design is reliant upon low power electronic components, they are inherently more susceptible to electrical transients as well as extreme temperatures as compared to electro-mechanical relays. Most electronic relays are more shockproof than electro-mechanical relays. Examples of analogue electronic relays include models RACID and RADHA. This relay technology is now only applied in a few relays types (2C137 Master Earth Fault relays) and has limited usage into the future and will soon be fully superseded by digital relays.

Digital/numerical relays

Digital/numerical relays are the next step after analogue electronic in the application of electronic technologies. Digital relays where first introduced into the network during the 1990s and provided even greater sensitivity, faster operation, enhanced flexibility, faster reset times, lower VA burden, greater accuracy and reduced size, all at a lower cost. They also offer many other ancillary functions such as programmable control logic, event recording, fault location data, operational metering, circuit breaker control, adaptive settings, remote setting capabilities, peer-to-peer communications, and self-monitoring and diagnostic features. Digital relays sequentially sample and convert the measured AC quantities (voltage and/or current) into digital signals (square wave binary voltages). Logic circuits or a micro-processor then compare the phase relationship of the square waves to make a trip decision. These digital relays comprise a number of basic components including an auxiliary power supply, analogue to digital converter, CPU, RAM and ROM. They are principally constructed from sensitive integrated electronic circuits. They usually have self-monitoring features which in turn reduce the need for preventative maintenance as the relay will report automatically when it is faulty. An example of such a relay type is the SPAJ. Numerical relays are those in which the measured AC quantities are converted into numeric data on which a micro-processor performs mathematical/logical operations in order to make a trip decision. Application specific algorithms, which replicate various protection and/or control operating characteristics, define the functionality of the relay. Almost all relays marketed today are of numerical technology. Examples of such relay types include the SEL351S, GE L90, GE SR760, SIEMENS 7SD511. Although modern microprocessor based numerical relays are different from the early digital relays in terms of design, functionality and capabilities, they are grouped together for the purpose of this life cycle management plan. Digital and numerical relays incorporate comprehensive self-monitoring routines and therefore require less preventative maintenance than their predecessors, namely analogue electronic and electro-mechanical relays.

There are over **200 unique models** of main protection and control equipment in-service across the network with a total population of approximately **1,766 relays**. Approximately 29% (521 relays) of JEN's relay population is remaining electro-mechanical technology. These relays were installed around 30 to 40+ years ago and were mostly imported from countries such as the United Kingdom with some being manufactured locally in Australia including some by the former State Electricity Commission of Victoria (**SECV**). Given their age, very few spare parts are available.

The remaining 71% (1,245 relays) of the population comprises relays based upon electronic technologies, with approximately 17% (292 relays) being analogue electronic relays and 54% (953 relays) being digital or numerical electronic relays. The vast majority of these relays have been imported from the United States of America, China, United Kingdom and other European countries including Sweden, Switzerland, Germany and France.

4.1.2 RISK

Protection and control systems are designed to detect the presence of faults or other abnormal operating conditions and to automatically isolate the faulted network by opening appropriate high voltage circuit breakers. Failure to isolate faults can result in severe damage to high voltage apparatus and may also cause an extreme HSE incidence (i.e. electrocution).

Interruptions to customers from faulty protection and control equipment are generally caused by either:

1. Failure of the protection relay to act upon a genuine fault; or
2. Mal-operation of the protection relay under system normal conditions.

Protection and control equipment exists to minimise damage to network assets (e.g. power transformer, switchgear, underground cable, etc.) during a network fault. Failure to isolate the fault due to relay failure will result in an increased likelihood of damage to network assets because of the energy available from the fault ($E=I^2t$). Reducing the fault current and/or the fault duration will help limit any damage. But, in most cases, reducing the fault current is not an option due to the required sensitivity setting of the protection scheme. Hence, both main and backup protection schemes are designed to isolate the fault as quickly as possible.

Protection relays are either duplicated or backed up by another relay to mitigate the risk for its own failure. This design philosophy helps to greatly reduce the risk of a network fault not being cleared, but often the total time take to clear the fault by backup protection is significantly longer and a greater number of customers are interrupted in clearing the fault.

An example of backup protection is a typical feeder protection relay backed up by a bus overcurrent protection relay. Failure of the feeder protection relay to detect and isolate a feeder fault would result in the bus overcurrent relay operating and tripping off supply to the entire bus (de-energising all feeders originating from that bus). This represents an unwanted interruption to a large number of customers. Had the feeder protection relay operated correctly in the first place, a smaller number of customers would be impacted. Additionally, the feeder protection relay would automatically re-close after five seconds (in about 75% of actual cases this clears the fault and restores power).

4.1.2.1 Criticality

Asset criticality assessment was conducted at the sub-asset class by following the Asset Criticality Assessment worksheet (JEM AM PR 0016). Results of this assessment can be found in Appendix A. Asset criticality scoring was then used to rank critical assets which have the potential to significantly impact JEN's operational objectives. This helps prioritise implementation of risk mitigation and control measures.

Protection and control sub-asset class has an asset criticality score of AC4 (High) due to the operational and health and safety consequence associated with failures. Protection and control equipment criticality (importance) is defined by:

- Impact on supply interruption when a protection fails to clear a genuine fault or mal-operates under system normal;
- Impact on network asset during faults (e.g. Power Transformers, Capacitor Bank, Circuit breakers, etc.) when a protection equipment fails to clear genuine network fault;
- Health and Safety risks associated with the failure of protection and control equipment for a genuine network fault;
- Impact on compliance requirement with the Electricity Safety Management Regulation and the Victorian Electricity Distribution Code; and
- Cost of replacement (approximately $100k for one relay replacement).

4.1.2.2 Failure modes

Failure of protection and control equipment can manifest itself as either:

1. A non-operation, that is, it does not operate when required to do so; or
2. An unwanted operation - or *mal-operation* - for either an out of zone fault or no fault at all.

4.1.2.3 Current risks

All risks are identified and managed in the Jemena Compliance & Risk System (JCAR).

The risk of protection equipment failing to operate or mal-operation are the two main risks associated with this sub-asset. Salient risks for this sub-asset class are:

- **Faulty protection relay fails to operate and isolate the network fault.** Consequence: 'Major'. Can result in death or serious injury (e.g. permanent disability, multiple hospitalisations, etc.) to personnel or a member of the public within proximity of assets exposed to hazardous voltages/currents due to uncleared fault. An additional consequence is **Fire Start**: potential to start a fire from downed conductors or conductors coming into contact with vegetation;

- **Faulty primary protection relay fails to isolate a network fault causing back up protection scheme to operate.** Consequence: 'Major'. Can result into loss of supply to large numbers of customers (approx. 15,000) for a long duration (approximately 60 minutes) leading to STPIS penalties; and
- **Faulty protection relay mal-operates in absence of network fault.** Consequence: 'Major'**.** Can result into loss of supply to large numbers of customers (approx. 15,000) for a long duration (approximately 60 minutes) leading to STPIS penalties.

Network faults are cleared as a matter of urgency. Failure to do so can result in:

- increased risk of damage to network assets as a result of the energy available to the fault;
- a serious risk to operating personnel and the public due to:
  - hazardous step and touch potentials due to ground currents at or remote from the fault location ;
  - electrocution from direct contact with energised conductors; or
  - fire starts from downed conductors or conductors contacting vegetation during high winds etc.
- risk of extended network outages impacting a greater number of customers.

4.1.2.4 Existing controls

There are three existing controls:

- Those detailed in the recommended condition monitoring and maintenance tasks together with initiation of replacement projects for assets determined to be at risk of failure;
- Online Monitoring. Modern secondary equipment employs comprehensive self-monitoring functions and diagnostic features. These relays are capable of reporting back to JEN's Co-ordination Centre via SCADA when it is faulty; and
- Spares. JEN has a comprehensive spares management system in place for protection and control equipment which ensures the availability of healthy and serviceable spares in the event of protection equipment failure.

4.1.2.5 Future risks

Emerging risks for this sub-asset class are:

- Cyber Security. Unauthorised access to protection and control equipment could cause service disruption and compromise the protection and control system. Funds ($1,900k) have been allocated to carryout evaluation of a secure access management system in the period 2021-2024;
- Ageing equipment means the likelihood of failure or mal-operation increases necessitating unplanned replacement;
- Deteriorating electro-mechanical relay populations. Online monitoring is not supported, therefore JEN does not immediately know when they fail. Spare parts become unavailable necessitating unplanned replacement;
- Non-availability of components for old relay from suppliers/manufacturers. Old relays tend to become unsupported and may necessitate unplanned replacement;

- Expenditure prioritisation. Constraint of funds may cause deferral of replacement programs; and
- Damage caused by vandalism. There increasing evidence of malicious damage to JEN's exposed fibre optic cabling. This can compromise the protection and control system.

4.1.3 PERFORMANCE

4.1.3.1 Requirements

Performance expectations are assessed against the following criteria:

- Operational availability of protection and control system;
- A stable and reliable electricity distribution network; and
- Zero adverse Health, Safety and Environmental (HSE) impact.

Performance expectations are achieved through inspection, condition monitoring, preventative and corrective maintenance, condition based asset replacement as well as monitoring of performance against budgeted targets.

JEN is required to report the number of protection and control equipment failures impacting reliability and/or health and safety to Energy Safe Victoria (ESV) every three months. This does not include relay failures identified during routine maintenance, continuous monitoring or annual inspection.

Protection and control equipment failures do not always result in impact to reliability and/or a HSE issue. There is a regulatory requirement for every protection relay to be either duplicated or backed up by another protection relay to mitigate the risk for its failure (the X and Y schemes).

Performance measures used to monitor the performance of protection and control equipment are:

- 100% operational availability protection and control system. This is measured by recording X and Y schemes 'up time';
- 100% NER compliance with respect to outage repair times (e.g. repair fibre optic cable with 8 hours). This is measured by reviewing field crew Incident Notification documentation; and
- 100% zero HSE incidents.

4.1.3.2 Life expectancy

A protection and control scheme is typically comprised of a main relay, associated AC and DC wiring, panel mounted switches, indicators and meters as well as auxiliary relays and other ancillary equipment necessary to provide the full functionality of the scheme. The main relay is the principal component in the scheme and is also considered the most likely element to fail. Thus the useful life of the main relay determines the useful life of the protection and control scheme. This approach simplifies the analysis for determining asset life and strategy. Any maintenance or replacement of the main relay also includes all associated equipment necessary to provide the full functionality of the scheme.

Nominal relay life expectancy

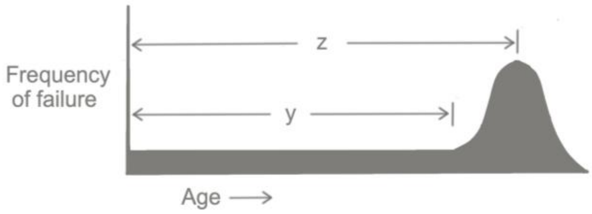
Relay technology	Nominal life expectancy
Electro-mechanical	40 Years
Analogue electronic	20 Years
Digital/numerical	20 Years

Criteria used to determine the life expectancy of a protection and control relay are:

- Relay technology time horizon (e.g. electro-mechanical, analogue electronic, digital);
- Historical data derived from preventative maintenance results and failures/defects;
- Manufacturer's warranty;
- Degree of manufacturer support (repairs, spares, engineering expertise); and
- Industry norms.

The useful life of a relay is not an exact science. It is a window of time where it is expected that a particular relay type is likely to start to exhibit signs of irreversible deterioration in performance.

Figure 7 – Relay life expectancy characterised using Weibull distribution



For a given population of relays of the same age and similar design and construction, the likelihood of failure during the useful life period 'y' is relatively low and assumed to be constant. 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 'z' 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).

Electro-mechanical relays

Electro-mechanical relays. History shows that a life expectancy of 40 years is a realistic for electro-mechanical type relays. Manufacturer's estimates have been open ended with many claiming that electro-mechanical relays will continue to operate satisfactorily provided regular preventative maintenance is performed. The existing preventative maintenance cycle is 8 years for this relay type (an industry norm).

Details of electro-mechanical relay failure modes for different relay types are

- CDG relays have shown significant timing errors that are an indication of the relay losing magnetism; significant timing errors reduce grading margins with upstream or downstream protection relays and greatly increase the risk of unwanted protection operations;
- TJV relays have also been observed to be losing their magnetism thereby adversely affecting their time current characteristic;
- The majority of the PBO relays were replaced, because they had shown significant timing errors. This is an indication of the relay losing magnetism; significant timing errors reduce grading margins with upstream or downstream protection relays and greatly increase the risk of unwanted protection operations;
- RI relays have a continuously rotating disc and require that the disc bearing be lubricated regularly. The bearing wears and periodically the disc pivot must be reground and polished for permit reliable timing. Facilities to do this are not available;
- CMG relays have bearings that suffer from stiction (static frication). That is, after a prolonged period of non-operation, a higher than expected current is needed for initial operation although successive operations will be at the lower current value calibration point;
- DS5, DSF7 and DL4 relays are pilot wire relays in which relays are installed at both ends of a line and connected by a pair of wires (pilots) in a supervisory cable. Although the relays are of an age where continued reliable service is in doubt, the supervisory cables that connect the relay pair have deteriorated and failures are common. Pilot failure can cause both failure to operate for a fault and operation for non-fault conditions. When a pilot failure is detected the relays can be transferred to an alternative pilot circuit through an exhaustive calibration process, however due to previous cable failures alternative circuits are far less likely to be available. Pilot wire relays are installed on all 66 kV lines except where they have already been replaced because of Supervisory Cable issues by Digital Current Differential relays that operate on fibre optic or other digital bearers; and
- RDW and PCD relays are directional relays that allow overcurrent protection to operate when the current flow is in one direction only. Bearing problems with these relays may cause them to jam so that either an overcurrent operation occurs when not required or no overcurrent operation can occur.

Similar relay defects and performance issues have been observed across the Victorian electricity supply industry. In most instances these defects can be rectified during preventive maintenance (subject availability of spare parts). However, the ability to rectify such problems during maintenance is becoming increasingly untenable because they have a limited range for mechanical adjustment and once exhausted it is not possible to keep the relay in-service.

Analogue electronic relays

Analogue electronic relays. The electronic components used in this relay technology are susceptible to electrical transients as well as temperature extremes that impact life expectancy. Additionally, age-related drift in component characteristics occur, affecting relay measurement, and many component semi-conductors are no longer manufactured. This type of relay also requires an auxiliary DC power supply that is found to be a point of failure, particularly in relays of an older design.

Some analogue electronic relays nearing 20 years in-service age are exhibiting signs of end of life deterioration, namely:

- Output contacts on RACID relays fail to open;
- A 2C135 relay failed to operate due to an overheated resistor in one instance; and

- Another 2C135 relay minimum operating setting was found to have drifted.

Low manufacturer support and spare parts availability for analogue electronic relays is a constraint.

Digital/numerical relays

Digital/numerical relays. These relays require an auxiliary DC power supply to provide the relay's sensitive electronics with the necessary low voltage supply rails (e.g. 5VDC). Auxiliary DC power supplies are known for their relative poor reliability; in particularly the electrolytic capacitors used for filtering the DC output are susceptible to premature failure. In addition, the auxiliary DC power supply also takes the brunt of most electrical disturbances in the zone substation DC supply system. Power supply reliability in relays of newer design appears to be more robust.

Recent discussions with relay manufacturers has provided a level of confidence that life expectancy is 20 years. The average age of this relay type in the JEN network is 8.4 years with the oldest digital relays being not more than 27 years. This means limited data exists to more accurately confirm the useful life expectancy. Digital relays are not expected to last any longer than the analogue electronic type relay.

Some manufacturers issue regular service bulletins that notify of known problems in a given relay make/model and typically include recommendations to address the problem. Problems in digital relays are typically caused by programming bugs and are usually addressed via a simple firmware upgrade. In rare cases a hardware upgrade may be necessary. In some instances, the service bulletin does not directly impact the JEN application of the relay and no action is taken. Firmware versions are upgraded if there is a genuine risk to the safe and reliable operation of the protection and/or control scheme that uses the relay.

Earlier generation of digital/numerical relays such as SPAJ 140C, SPAJ 160 and GE SR Series relays have been failing across network recently due to power supply module failures. This has caused JEN to bring forward replacement works at selected zone substations.

Each generation of relay technology has introduced new capabilities and features that have enhanced the flexibility and functionality of the relay. Digital relays are designed with comprehensive self-monitoring and diagnostic systems that are integrated into the zone substation's remote alarm system such that any failure is immediately reported at the JEN Control Room via the SCADA network. This feature greatly reduces the risk of relay non-operation under a genuine network fault condition, and avoids the situation of a latent condition persisting until becoming apparent by failure to operate when required. Additionally, digital relays are generally designed to be fail-safe, that is, not to operate if the relay detects an internal problem.

Strong manufacturer competition over the last 20 years in a rapidly developing technological environment of ever-faster processors and ever-increasing RAM capacity has introduced the dynamic of rapid obsolescence. Version-creep for a relay model can impact on spare relay stock requirements and compatibility of relay setting files when replaced. Some first generation microprocessor relays cannot be accessed by 21st century laptop computers.

4.1.3.3 Age profiles

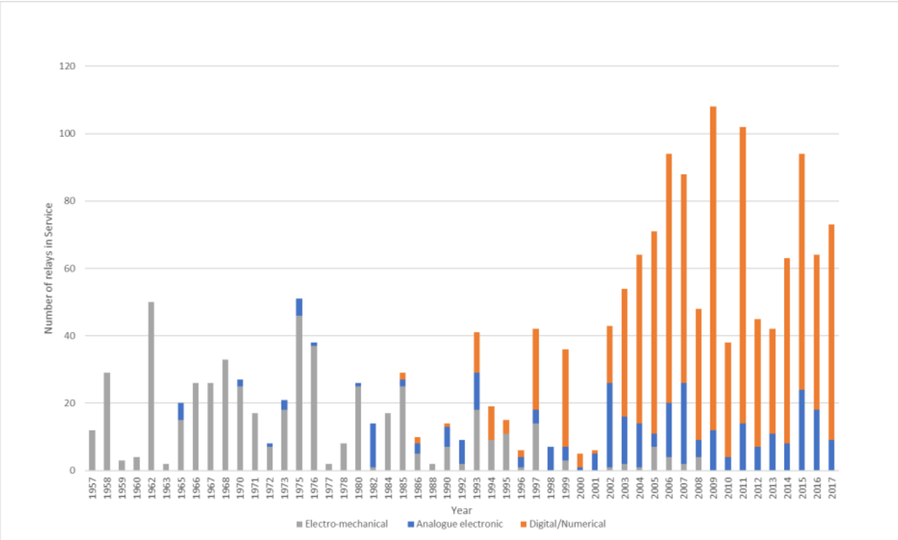
The average age of electro-mechanical relays is 42 years. Relays of this technology are still being installed in very low numbers. These new relays have simple functionality and operating mechanisms and are technically fit-for-purpose (depending upon the context of the substation).

These new relays lower the average age of the installed relays of the electro-mechanical class of relays. Approximately 74% were installed prior to 1980 (i.e. have been in-service for 40+ years).

The average age of analogue electronic relays is 14 years. Relays of this technology are still installed in low numbers in applications with simple functionality and technically fit-for-purpose (depending upon the context of the substation). These new relays lower the average age of the installed relays of this analogue electronic relays. 53% of these analogue electronic relays were installed prior to 2006 (i.e. have been in-service for 13+ years).

The average expected operating life of protection and control equipment is around 40 years for electro-mechanical (EM), 20 years for analogue electronic (AE) and digital/numerical (DI) relays. The average age of installed electro-mechanical type relays is 42 years with some relays now approaching 50 years. The average age of analogue electronic type relays is 14.1 years and the average age of digital/numerical relays is 8.4 years.

Figure 8 – Relays in service by year of installation



4.1.3.4 *Utilisation*

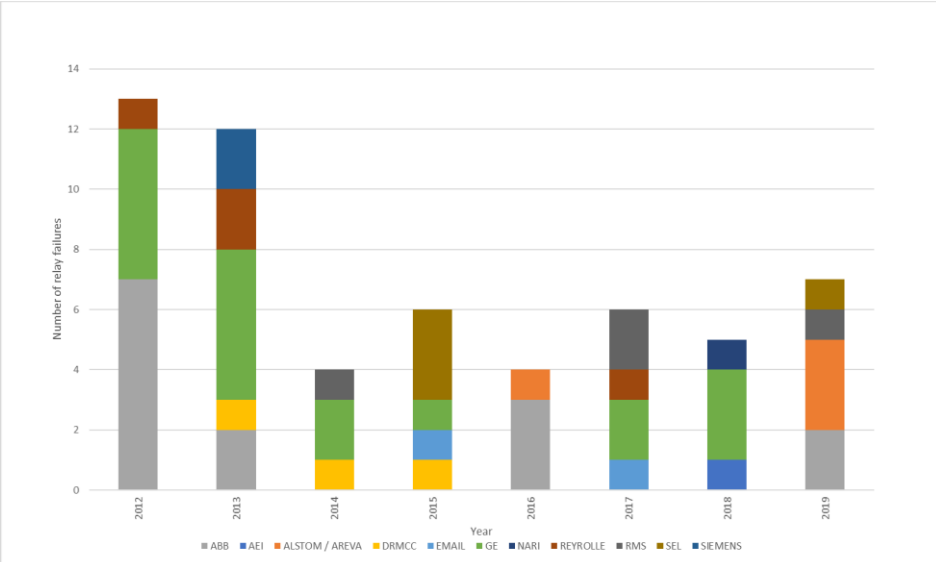
Protection and control equipment is kept in-service continuously to monitor and detect the presence of network faults and/or other abnormal operation conditions.

4.1.3.5 *Performance analysis*

When a protection relay fails or mal-operates, root cause analysis is performed. Findings are recorded and reported with associated network impact figures (e.g. SAIDI, SAIFI and MAIFI).

Since 2012 there has been, on average, 7 relay failures per annum. In only one instance did a widespread outage result from relay failure.

Figure 9 – Relay failures by year



There are a number of issues relating to the reliable operation of zone substation protection and control equipment, namely:

- SPAJ relays;
- GE SR relays;
- Deteriorating electro-mechanical relays; and
- Summation of multiple CT cores on Current Differential Protection Relays.

There are ongoing failures of SPAJ relays. ABB SPAJ140C and SPAJ160C are early generation digital relays installed on the network in the early 1990's. These relays have been failing recently due to power supply module problems. This problem is a manufacturer design weakness so repair is not a long-term solution. These relays have been targeted for replacement.

There are ongoing failures of GE SR relays. GE SR 750 and SR 760 relays are also early generation digital relays installed on the network that have been failing recently due to power supply module problems. This problem appears to be a design weakness so that repair or direct replacement is not a long-term solution and, these relays, installed at various substations, have been targeted for replacement.

A large number of deteriorating electro-mechanical relays older than 40 years are exhibiting signs of end of life deterioration. Recent periodic maintenance on these relays has shown significant timing errors, an indication of weakening in strength of the braking magnet. In most instances these timing errors have been rectified during preventive maintenance. However, as previously noted, most electro-mechanical relays have a limited range of mechanical adjustment and once that limit is reached it is not possible to keep the relay in-service. Zone substations at Broadmeadows (BD), Braybrook (BY), Coburg North (CN), Coburg South (CS) and Footscray West (FW) with electro-mechanical relay installations have also been targeted for relay replacement.

Summation of multiple CT cores

In 2018 there were two zone substation incidents associated with summation of multiple CT cores outside Current Differential Protection relay. One incident was at Coburg (COO) and the other at Airport West (AW). This design practice is not to be used for future builds as the relay is unable to generate sufficient restrain current to stabilise the scheme for CT saturating caused by through fault (aka Out of zone fault).

As a result, the relay will mal-operate for a through fault scenario leading to complete loss of the zone substation.

The key lessons from the incidents at AW and COO are:

- In practice, it is rarely possible to completely prevent the occurring of CT saturation as it is not practical to oversize a CT to cater for DC offset and remanence;
- Current differential protections are susceptible to CT saturation and if not correctly implemented (i.e. paralleling CT's outside) then they are not able to restrain CT saturation;
- Repeat of similar incidents across the network can potentially lead to either:
  - Loss of supply to the 22kV or 11kV bus (5000-10,000 customers per bus); and
  - Loss of supply to the entire station(15,000-20,000 customers per zone substation). Similar to a Coolaroo zone substation incident in early 2018.

In order to prevent recurrence of such incidents it is required that the above issue be considered and the following adopted, were practical, for all future projects:

- Installation of Line CB's for station without line CB's to avoid paralleling multiple CT's outside the relay;
- Retrofitting the existing primary plant (e.g. Transformer or CB) with an adequate number of CT cores to avoid the use of interposing CT's; and
- Avoid extending the Transformer Differential protection to protect the 66kV Bus.

4.1.3.6 Control effectiveness

The three principle risk control are maintenance, on line monitoring and spare management. These are proven to be highly effective.

Effectiveness of risk controls is informed by the track record of condition-based replacement projects. A list of these is provided at 7.3 APPENDIX C – *Protection & Control – History of CAPEX replacement initiatives.* By comparing identified risks and measuring actual incidents, an assessment of the effectiveness of the existing controls is tabulated.

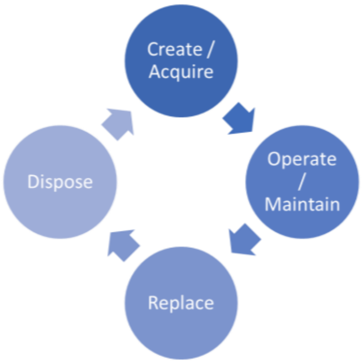
Figure 10 - Effectiveness of the existing controls

Risk category	Cause / incident	Control	Incidents in past 5 years
Health, Safety & Environment	Protection failure results in environmental damage or injury to personal	▪ Asset Management strategy applied ▪ Replacement projects completed	Nil
Regulatory & compliance	Protection failure or mal-operation results in non-compliance notice	▪ Asset Management strategy applied ▪ Replacement projects completed	Nil
Financial	Protection failure or mal-operation results in significant unplanned cost	▪ Asset Management strategy applied ▪ Replacement projects completed	Nil
Operational	Protection failure results in loss of supply to customer OR Protection mal-operation results in loss of supply to customer	▪ Asset Management strategy applied ▪ Replacement projects completed	One (Loss of supply to Coburg when Transformer protection mal-operated)

4.1.4 LIFE CYCLE MANAGEMENT

4.1.4.1 Creation

Sub-assets in this class are effectively created via acquisition or the deployment of spares. The following scenarios trigger the need to acquire and connect new protection and control equipment:



1. As part of a new zone substation development
2. As part of an existing zone substation capacity upgrade
3. To replace aged and deteriorated relays that have reached end of life
4. Functional and/or performance improvement driven change
5. Change in regulatory requirements
6. Customer driven requirements (e.g. sensitive major HV customer, embedded generation, etc.)
7. Performance and/or safety driven network projects (e.g. installation of Neutral Earthing Resistor, installation of Restricted Earth Fault Current Limiter, etc.)
8. Specific asset owner requirements

Spares management

The availability of spare protection and control equipment is a critical element of this sub-asset class strategy. Spare equipment is required in the event of a defect or failure so as to re-instate full or part functionality of the protection and control scheme in the shortest possible timeframe.

Currently there are a limited number of spare relays for the relays in-service. This is mainly due to deficiencies in the spare equipment management system that would ensure that the necessary spares are held. A secondary equipment spare database is currently under development to address this issue.

The objectives of the spares plan are:

- Minimise outage times of the protection and control scheme e.g. speedy replacement;
- Minimise network risks associated with any abnormal system arrangement that may be required in response to a protection and control equipment failure, e.g. failed feeder protection scheme would require the feeder load to be transferred away to adjacent feeder(s);
- Avoid or minimise field and engineering resources associated with re-instatement of the defective protection and control scheme;
- Minimise re-instatement costs;
- Minimise any impact to customers; and
- Minimise the cost of holding spares, that is, to keep the total spares inventory to a minimum.

Like for like replacement of faulty relays is preferred. However, given the large number of different relay models currently in-service across the JEN, it is considered impractical both from a physical and an economic perspective to hold an identical spare for each unique model of relay.

Figure 11 - Quantities of protection and control spares

Relay type	Quantities	
	Minimum	Maximum (as % of total population)
Electro-mechanical	2	5% (1 in 20)
Analogue electronic	2	2% (1 in 50)
Digital/numerical	1	2% (1 in 50)

The recommended maximum number of spares is a percentage of the total in-service population of the particular relay model or aggregate of similar relays models that can be functionally grouped.

The number of spare relays for in-service numerical relays is influenced by the time to repair, involving return of the relay to its off shore manufacturer, and availability of sufficient spares in the meantime.

The recommended minimum number of spares are:

- **Case 1 -** The population of a unique relay model is equal to or greater than 20;
- **Case 2 -** The population of a relay grouping or 'family' is equal to or greater than 20;

- **Case 3 -** A spare already exists; and
- **Case 4 -** A special case.

Case 1: In this case, for example, a spare Schweitzer SEL-0351S6XHD4FB462 type relay would be kept as spare for a population of 20 plus identical SEL-0351S6XHD4FB462 type relays. This approach effectively eliminates the need for costly ad-hoc engineering and field effort during the changeover process as it permits a straight forward like for like replacement. The "0351S6XHD4FB462" identifier is the unique order code for the SEL351S relay used on the JEN network.

Case 2: Where it is possible to group a number of unique models of the same relay make into a 'family' such that a higher specification model can be used to replace any model within that family, then the higher specification model shall be used as the spare for that family. For example, an Areva MiCom P127 relay can be used as a spare for itself as well as the P126 and P125 relay models (this being the MiCom P12x family). Likewise, a P123 relay can be used as a spare for itself as well as the P122, P121 and P120 relay models. It is acknowledged with this option that some additional engineering and field effort may be required in the changeover process that would have otherwise been avoided with a true like for like replacement (option A). However, this approach recognises that there are many relay types (in small numbers) that can be grouped into families which will therefore minimise the overall number of unique relay spares required for the JEN electricity network. If in the event a lower specification relay within the family fails and it is replaced with the higher specification spare, then a new spare will be procured to replenish the spare stock but the new spare will again be the higher specification relay. If the faulty lower specification relay can be repaired at a reasonable cost then it should be and then returned to spare stock. Careful management is needed for the possibility that the manufacturer may supply a new relay or return a repaired relay with upgraded (current production) firmware that is incompatible with standard setting files.

Case 3: If the spare already exists in stock (this will generally apply to the older electro-mechanical type relays). In this instance, the existing relay spare(s) will be retained up to the recommended maximum spares quantity.

Case 4: It is acknowledged that in some instances an identical spare will be required for a given relay model irrespective of the existing population, this being based upon an assessment of the relay risk profile among other things. In such circumstances a minimum of one identical relay spare will be sourced if it is practical.

As the relays in-service population increases (e.g. due to natural network growth or planned replacement projects), spare inventory shall increase proportionally. Spares will be sourced from one or more of the following sources:

- Purchase from supplier; and
- Free up spare(s) from existing in-service population via a planned relay replacement.

If a spare cannot be sourced, a contingency plan is formulated to:

(i) Document the best course of action: and

(ii) Implement a proactive replacement plan (or the application of a universal spare).

Protection and control equipment spares are safely stored in a secure and stable environment at Tullamarine. The store location is readily and easily accessible 24 hours 7 days a week for appropriate field staff.

New or recycled equipment is subjected to a quality check before it is put into store. Spares that do not pass the quality check are repaired or disposed of.

A periodic maintenance regime will be applied to all spare protection and control equipment in accordance with manufacturer recommendations so as to ensure that the spare equipment is serviceable. For example, relays with auxiliary power supplies (analogue electronic, digital and numerical) are routinely energised (power cycled on/off) every 4 years to prevent dry out of electrolytic capacitors in the power supply circuits.

There is a spares management system in place to ensure that the recommended spares are held in storage. Traditionally, spares have been purchased as part of all capital projects that involve the installation of protection and control equipment. However, adoption of a new spares purchasing policy such that spares are only sourced when required to satisfy the minimum number of spares ensures that spare equipment is not purchased unnecessarily.

An audit of all JEN protection and control spares is carried every 5 years to determine what spares are needed and which spares are no longer required.

Based on the above, the requirement for spares is reflected in the CAPEX forecast of $254k.

4.1.4.2 Operation and maintenance

Protection and control equipment maintenance is performed by trained and experienced personnel. The equipment used to test and service JEN's protection and control asset population is regularly inspected, calibrated and certified to the requisite specification and standard.

The results of all secondary plant maintenance tests are recorded and electronically stored for future reference. Test results are captured and collated in a proprietary software package, namely Doble's Protection Suite. Any abnormal performance results are analysed and corrective action determined.

This sub-asset maintenance program involves:

- Preventive maintenance; and
- Reactive maintenance.

Preventative maintenance consists of continuous monitoring and inspection and testing for each of the relay types.

Preventative maintenance of **electro-mechanical relays** consists of:

Electro-mechanical relays

Preventative

- Visual inspection of relay for corrosion, rodent and insect damage, water and other physical damage;
- Remove any foreign objects such as excessive dust etc;
- Clean and adjust output contacts etc;
- Confirmation that applied settings reflect settings captured in RESIS;
- Min-op tests via secondary current injection;
- Timing tests via secondary current injection;
- Stability tests via secondary current injection;
- Functional checks of the relay (trip checks, initiation of reclose and CB fail, targets, annunciations and alarms);
- Check for setting drift (compare with previous maintenance results);
- Re-calibrate relays as required;
- Check inter-relay communications (pilot wire on-loads);

- Visual inspection of all scheme wiring, terminals, test links, panel mounted switches & indicating lights etc. Including checking tightness of all connections;
- Check insulation resistance of all wiring and cabling to earth and between electrically separate circuits;
- Confirm readability of labelling and clean or replace as required; and
- On-load tests to verify that equipment transformer (CTs and VTs) and other measuring transducers are providing the correct signals to the relay.

Preventative maintenance of **analogue electronic relays** consists of:

Analogue electronic relays

Preventative

- Visual inspection of relay for corrosion, rodent and insect damage, water and other physical damage;
- Remove any foreign objects such as excessive dust etc;
- Clean and adjust output contacts where possible;
- Confirmation that applied settings reflect settings captured in RESIS;
- Min-op tests via secondary current injection;
- Timing tests via secondary current injection;
- Stability tests via secondary current injection;
- Functional checks of the relay (trip checks, initiation of reclose and CB fail, targets, annunciations and alarms);
- Check inter-relay communications (communications errors);
- Visual inspection of all scheme wiring, terminals, test links, panel mounted switches & indicating lights etc including checking tightness of all connections;
- Check insulation resistance of all wiring and cabling to earth and between electrically separate circuits;
- Confirm readability of labelling and clean or replace as required; and
- On-load tests to verify that equipment transformer (CTs and VTs) and other measuring transducers are providing the correct signals to the relay.

Preventative maintenance of **digital/numerical relays** consists of:

Digital/numerical relays

Preventative

- Visual inspection of relay for corrosion, rodent and insect damage, water and other physical damage;
- Remove any foreign objects such as excessive dust etc;
- Confirmation that applied settings reflect settings captured in RESIS;
- Functional checks of the relay (trip checks, initiation of reclose and CB fail, targets, annunciations and alarms);
- Check inter-relay communications (communications errors);
- Replace relay battery (if fitted) in accordance with manufacturers recommendations;
- Check, review and download all event and disturbance records;
- Confirm operation of relay watch-dog alarm and check receipt of station relay fail alarm at the Co-ordination Centre via SCADA;
- Visual inspection of all scheme wiring, terminals, test links, panel mounted switches & indicating lights etc including checking tightness of all connections;
- Check insulation resistance of all wiring and cabling to earth and between electrically separate circuits;
- Confirm readability of labelling and clean or replace as required; and
- On-load tests to verify that equipment transformers (CTs and VTs) and measuring transducers are providing the correct signals to the relay.

Digital/numerical relays are designed to be essentially maintenance free with the majority of their internal operations being automatically checked by self-monitoring circuitry within the relay. Repeatability without settings drift is an inherent benefit of digital technologies and therefore the following traditional maintenance tasks are not required for this relay type:

- Min-op tests via secondary current injection;
- Timing tests via secondary current injection; and
- Stability tests via secondary current injection.

Zone substation secondary equipment, including protection and control equipment, is audited annually by the Secondary Plant team. Secondary equipment audit consists of:

- Visual inspection of all secondary equipment for cleanliness; and
- Visual inspection of all secondary wiring, terminals, test links, panel mounted switches & indication lights.

The aim is to minimise preventative maintenance as far as practicable and maintenance intervals have been aligned with current industry standards. Maintenance requirements have been customised depending upon the relay type, condition of the relay and other factors including the relay age profile. Once maintained, it is assumed that the protection and control equipment will perform reliability at least up until the time that it is next maintained.

If a particular type or family of relay begins to exhibit symptoms of performance degradation, then that relay population will be more closely monitored. This may require an increase in the preventative maintenance frequency. The maintenance tasks may also be customised accordingly to address a specific issue or issues.

Furthermore, if deteriorated protection and control equipment is not replaced at its nominal end of useful life, any known issues with the relay may require a reduction in preventative maintenance intervals. For example, an increased rate of drift in a measurement characteristic can be addressed by more frequent recalibration. It is also acknowledged that the risk of relay failure may increase as a result of over maintenance.

Routine preventative maintenance is performed on protection and control equipment at a nominal 8 years interval excluding sub-transmission line protection schemes. Maintenance on sub-transmission line protection needs to be coordinated with AusNet Services. It is a requirement to maintain all 66kV line protection equipment every three years due to regulatory requirements imposed on the transmission business.

Figure 12 – Preventative maintenance intervals

Protection scheme	Maintenance cycle
66kV Line Protection Scheme (Line Differential and Pilot Wire Schemes)	Once every 3 years
All other Protection Schemes	Once every 8 years

Preventative maintenance plans are held in SAP and regularly reviewed so as to accommodate any planned relay replacement program. This ensures that maintenance is not unnecessarily performed on relays due for replacement.

Reactive Maintenance

Protection and control equipment faults are typically identified after an investigation arising from an abnormal operation or lack of operation. They may also be identified during preventative maintenance or via some form of health condition monitoring with an alarm received in the Co-ordination Centre via SCADA. Faults are urgently addressed as they represent an issue or problem that may impacted the performance and/or intended operation of the equipment.

Reactive maintenance consists of:

- Repair within 24 hours; and
- Replacement (with a spare) within 24 hours.

4.1.4.3 Replacement/disposal

Generally there are three maintenance modes available for this sub-asset life cycle management. The alternative sub-asset replacement modes are:

- Run to failure (reactive);
- Schedule-based replacement (age-based); and
- Condition-based replacement (the most cost effective).

Run to failure means replacement occurs reactively upon failure (irrespective of age or condition). This mode is not desirable because it would result in numerous unwanted failures and contravenes the required robust level of protection. Resultant ad-hoc replacement would require unplanned primary plant outages. Spare relay stock would be exhausted after a few failures, with repair or purchase of older relays not possible. In that event, modern equivalent relays would need to be installed on a piecemeal basis resulting in higher design and installation costs than a the alternative two modes.

Schedule-based replacement. This mode proposes to replace protection and control equipment at the end of design/product life. This accepts escalating activity to keep the asset in-service near the end of its design/product life, or earlier, may be necessary. A larger stock of spare relays, and/or a repair facility is required, although the replacement of all relays at the end of their design/product life would be carried out in a controlled manner.

Condition based replacement represents the best value because it precludes ‘run to failure’ and improves upon ‘schedule based replacement’ by incorporating age data into overall condition monitoring of the asset. This facilitates the optimal trade-off of CAPEX and OPEX. However some assets are easier to monitor than others, for example:

- Modern digital/numerical relays are designed with comprehensive self-monitoring and diagnostic systems which are integrated into the zone substation’s remote alarm system and any failures are immediately reported to the JEN Co-ordination Centre via the SCADA network; and
- Legacy electro-mechanical relays do not have self-monitoring features. But these relays are monitored via an annual zone substation inspection program and a comprehensive routine maintenance program. Therefore a sudden failure of these relays is unlikely.

Other factors that contribute to the replacement of protection and control equipment are:

- functional and/or performance improvement driven change;
- changes in regulatory requirements;
- customer driven requirements (e.g. sensitive major HV customers);

- demand and/or performance driven network projects (e.g. transformer project, installation of neutral earthing resistor); and
- specific asset owner requirements.

The diversity in relay types used across the JEN network is a reflection of the different design philosophies and purchasing practices employed in the past. The evolution of relay technology over the past 30-40 years is also a contributing factor to this diversity. For more efficient management of these assets into the future, it is desirable to reduce the number of unique relay models in-service across the network. To help facilitate this longer term objective, significant work continues on the ongoing development of secondary design standards using a short list of preferred relay makes and models.

The replacement strategy applied to protection and control equipment is principally condition based using available asset data. The age of a relay plays a key role in determining the replacement strategy as protection equipment should not have a 'run to failure' mode due to the critical nature of this equipment. The key criterion used to determine the replacement age is the nominal 'useful life' for each type of relay technology. Other criteria are spares availability, realistic repair expectations, orphan relays and maintenance workforce availability.

From a CAPEX point of view, there are two condition based replacement choices:

- Fragmented replacement; and
- Bulk replacement.

Fragmented replacement. Fragmented replacement would see the replacement of specific makes and models of protection and control equipment, that is, only those relays that are not fit for service based on condition or exhibiting symptoms of aged related deterioration. This gradual replacement of protection and control equipment within a zone substation may appear cost effective but it is not economic in the long term. A gradual relay replacement leads to variations in design and setting variations in the exact type of relay supplied and increases scope for error. Moreover, piecemeal replacement is expensive and not considered as prudent asset management. An exception would be in having orphan or maintenance intensive relays eliminated.

> Approximately 500 protection and control relays are at, or nearing, end of life. This means crucial capital expenditure. Two tactical options are
>
> - Fragmented replacement
> - Bulk replacement at nominal end-of-life

Protection and control equipment is highly integrated with other components within the station including AC supplies, DC supplies and primary plant and equipment. Direct relay replacement may not be possible due to lack of spare relays and inability to purchase new relays of an obsolescent type. Replacement with a new relay of a different type may be difficult and often impractical to affecting other parts of the zone substation design. Most often sub-optimal designs are required in order to integrate new technology hardware into ageing legacy designs.

This approach is not an efficient use of design and field resources as they need to keep re-visiting the same site as each replacement project is identified. Furthermore, this approach does not eliminate the risk of condition/aged related protection and control equipment failures and is therefore considered unacceptable.

Bulk replacement at nominal end of life. As mentioned above, piecemeal replacement of deteriorated protection and control equipment may appear economic in the short term, but it is not considered a prudent approach because of the variations in design and installation standards that result, management of station drawings, and variations in relay type, firmware and hardware versions. A time-based strategy of bulk relay replacement at the assessed end of life is therefore preferred and has been adopted in this asset class strategy. This approach is consistent with other electricity supply industry businesses and is considered good industry practice. The majority of protection and control equipment installed within JEN zone substations have the same or similar age profile, so this also support a bulk replacement approach.

The benefits of bulk relay replacement are:

- A significant reduction in overall project delivery cost due to a larger volume of work delivered at the same time. Replacement of deteriorated relays on a piece-meal basis is resource intensive and not cost effective;
- Realise the benefits offered by the latest relay technology through a more holistic and integrated design. Like for like replacement is no longer practical or desirable as modern relays are multifunction devices allowing for many legacy (single function) relays to be replaced by a single package without additional cost. Another example is the ability to implement peer to peer communications between relays and the station RTU, thereby minimising the amount of hardwiring within the station;
- Facilitates the transition to new secondary design standards;
- Opportunity to adopt future standards such as IEC 61850;
- Opportunity to implement a smart substation;
- Avoids complicated interfaces between new and legacy designs;
- Reduces the risk of unwanted protection operations during site works that would result in the loss of supply to customers;
- Simplifies the replacement of wiring, panels, cubicles, cabling, instrumentation and other interface equipment associated with the aged protection and/or control scheme;
- Improvements in construction documentation i.e. engineering drawings;
- Occupational health & safety considerations e.g. many older zone substations have relays mounted on insulated panels made from an asbestos reinforced material. Restrictions on the cutting and drilling of holes in these asbestos panels makes piece-meal relay replacement very difficult, expensive and impractical;
- Facilitates simpler and more cost effective life cycle management of the assets. Bulk replacement will prepare the zone substation for a similar bulk replacement in the future. This will ensure JEN is well positioned to take full advantage of new technological advancements as they develop in the future; and
- Eliminates risk of unwanted aged related protection and control equipment failures as the aged equipment is renewed (replaced) at end of life.

Replacing legacy electro-mechanical and analogue electronic relays with modern digital/numerical relays reduces preventative maintenance requirements because the newer digital relays are virtually immune from settings drift. In addition, digital/numerical relays ship with comprehensive self-monitoring functions so they can alarm minor and major problems in real time. This reduces the risk of non-operation and unwanted operations of the relay failure by not leaving a failed relay in-service. In the absence of comprehensive self-monitoring, the older relays carry the risk of failure without notice within the maintenance cycle period risking the network. Other benefits can be realised by replacing aged protection and control equipment with modern digital relays such as:

- the provision of detailed event records;
- fault waveform capture capability;
- user definable protection characteristics;
- programmable logic;
- wider setting ranges;
- an ability to integrate with host SCADA using standard serial communications protocols such as DNP3 and IEC 61850;

- remote access capabilities;
- significantly less wiring; and
- smaller footprint due to the integration of many functions into the one relay.

Condition/age-based bulk relay replacement is the most cost effective option

The replacement of condition and aged-based protection and control equipment has been aligned with the planned replacement of high voltage plant and equipment at the zone substation wherever possible, in particular where this involves the installation of new power transformers or high voltage switchgear, subject to a cost-benefit analysis. The alignment of asset replacement activities maximises the technical engineering benefits afforded by an integrated solution and also minimises the project delivery costs.

Disposal

Any faulty or decommissioned equipment is disposed of accordingly by a certified recycling company in accordance with Jemena Environment Policy (JEM PO 0397).

CAPEX and OPEX priorities

Relay replacement projects contend for inclusion in the capital works program. Business case proposals compete for priority in JEN's capital expenditure planning.

JEN looks at the sub-asset class CAPEX and OPEX proposals taking into account the consequences of not undertaking proposed works in line with the following table.

Figure 13 - Sub-asset Class strategic drivers

Strategic driver	Risk/opportunity description	Consequence
Asset Integrity	Failure of protection equipment	▪ Increase in Expected Unserved Energy to customers (EUSE) ▪ Negative publicity that impacts the brand or confidence of stakeholders (e.g. HV customers) ▪ Loss of supply to large number of JEN customers for an extended period ▪ Loss of supply to major HV customers (e.g. airports, hospitals, factories, etc.) ▪ Major damage to zone substation primary plant (e.g. Power Transformer, Circuit Breakers, Capacitor Banks, conductors/cables, etc.)
Safety, Health and Environment	Failure of protection equipment during fault scenario	▪ Serious injury ▪ Fatality

Historical CAPEX and OPEX performance helps inform expectations about future programs of work. An example of historical information is provided at Appendix C - *Protection & Control – History of CAPEX replacement initiatives.*

30% of JEN's relay population are electro-mechanical relays and are nearing, or have exceeded, their design/product lifetime.

Recent failures have also shown that the condition of number of relay models (e.g. SPAJ and GE SR series) have a known fault. As a result, beginning in 2016, replacement of those relays has been an ongoing project (until 2025).

CAPEX information about protection and control equipment proposed for replacement to 2026 is tabulated below. The estimated replacement timeframe is subject to adjustment depending upon the need to undertake other associated works at a particular zone substation so as to achieve resource efficiency and minimise any disruption to electricity supply.

Figure 14 – Protection and control relay replacement CAPEX

Location	Year	Reasons for replacement	Comments
BD / VCO	2018	1) Recent relay failures at BD; 2) Number of critical protection schemes such as bus and transformer protections do not have real time monitoring capability; 3) Condition of the BD relays; and 4) Criticality of BD ZSS as it supplies large number of customers including major HV customers.	1) This project is currently in progress 2) As part of the BD relay replacement project, BD-VCO 66kV Line protection will also be replaced. 3) A new control building is required to house the new secondary equipment at BD due to number of issues with the existing control building.
FW	2019/ 20	1) Transformer, 22kV Bus, 66kV Bus and Cap Bank Protections are deteriorated electrotechnical relays which need to be replaced urgently; 2) Majority of the relays are beyond their expect life; and 3) CDG relays without real time monitoring feature.	1) Relay replacement at FW is aligned with the FW 22kV switchgear and 66kV CB replacement project.
BY	2021	1) Concerns over the feeder protection relays as these feeders are protected by SR760 relays; 2) No.1 22kV Bus protections are also scheduled for replacement; 3) Existing Transformer protection relay is SR745 which has a history of failure due to faulty power supply module; and 4) Existing Transformer protection relays are extended into the 66kV bus with the CT's summated external to the relay which is not ideal as the relay can mal-operate when CT's saturate.	1) N/A
FE	2021/ 22	1) 22kV Switchgears at FE is scheduled for replacement in 2021. 2) From previous experience, it's evident that the business will incur approximately 70% of the relay	1) Relay replacement is combined with the FE Switchgear replacement project. Funds are allocated in the

Location	Year	Reasons for replacement	Comments
		replacement cost to retain an existing relay when a CB or switchgear is replaced. 3) Hence, the following relays at FE are to be replaced as part of the switchgear replacement project: a. 22kV Feeders; b. 22kV No.1 & No.2 Bus c. Cap Bank Prot; d. BUEF Prot; e. All CBM relays; f. MEF; and g. Local Alarm Panel	switchgear replacement project.
CN	2022/ 23	1) Mitigate Risks Associated with Deteriorated Relays - CN	1) New building is required at CN to facilitate relay replacement. 2) Align with the Switchgear replacement project at CN.
CS	2023/ 24	1) Mitigate Risks Associated with Deteriorated Relays - CS	1) Align with the Switchgear replacement project at CS.
NH/NEI	2024/ 25	1) Mitigate Risks Associated with Deteriorated Relays - NH / NEI 2) Serious concerns with the existing 66kV line Pilot Wire protection scheme.	1) Align with 22kV switchgear replacement project at NH.
NS	2025	1) Mitigate Risks Associated with Deteriorated Relays – NS. 2) Serious concerns with the GE SR series relays.	1) Replace all outstanding relays at NS which were not replaced as part of the NS Transformer replacement project in 2017.

4.1.5 INFORMATION

JEN's AMS (Section 1.2 above) provides a hierarchical approach to understanding the information requirement to achieve Jemena's business objectives at the Asset Class. In summary, the combination of Jemena's Business Plan, the individual Asset Business Strategy (ABS) and Asset Class Strategy (ACS) all provide the context to determine the information required to deliver the sub-asset class' business outcomes.

The high-level information requirements to achieve the ACS's business objectives and inform its critical decisions were identified at a facilitated workshop during the ACS definition process. The protection and control sub-asset class identified two business objectives together with the business information required to support these objectives set out in *Figure 15*. Current and future information requirements to inform value-add decision making are at *Figure 16*. A proposed improvement future business information need is at *Figure 17.*

Figure 15 - Protection and control equipment business objectives and information requirements

Business objective	JEN information sources	Externally sourced data
Protection & Control – to minimise the damage to network assets and risk to personal due to network faults	▪ DrawBridge ▪ SAP ▪ RESIS ▪ Protest Database ▪ SCADA ▪ ECMS	▪ SAI Global – AS/IEC Standards ▪ Manufacturer technical manual ▪ Industry Fault History ▪ Alerts from manufacturer

Figure 16 - Protection and control equipment critical decision business information requirements

Critical business decision	Current information usage	Future information requirement	Value to asset class (High, Medium, Low with justification)
Protection & control equipment – asset creation	▪ Specification and tender responses ▪ Asset register in SAP ▪ Asset information in RESIS		High - Regulatory obligation to maintain network continuity and security of supply and safety
When to maintain and replace pretention & control equipment	Asset register in SAP with details of each assets ▪ Relay Functional Location ▪ Manufacturer Model ▪ Equipment Description ▪ Installation Date ▪ Relay Technology ▪ Location: zone substation Asset Defect Register: ▪ Event description ▪ Relay Model ▪ Date and time ▪ Notification Number	▪ Require published figures of relay failures – worldwide ▪ Predictive analytics of condition of relay. Relies on a consolidated view of data ▪ Performance indicator for the relay -E.g. % of availability ▪ Photograph of relay nameplate and attach to SAP equipment ▪ Unit cost of relay replacement	High - Regulatory obligation to maintain network continuity and security of supply and safety

	Protest – Maintenance records ▪ Test results ▪ Tester comments DrawBridge: ▪ Single Line Diagram ▪ Protection Schedule ▪ AC, DC and Logic Diagram Performance History: ▪ Daily Situation Report (DSR) ▪ Incident Investigation Reports (ECMS)		
Respond to relay defects to restore equipment operationally. Perform corrective maintenance	▪ Alert via NOC or Daily Situation Report. ▪ Asset Defect Register	▪ All defect data to be collected and stored within SAP to enable effective root cause and performance analysis	High - Regulatory obligation to maintain network continuity and security of supply and safety

Figure 17 – Information initiatives to support business information requirements

Information initiative	Use case description	Asset class risk in not completing	Data quality requirement
▪ Require published figures of relay failures – worldwide	▪ To improve analysis and decision making.	▪ Unable to effectively manage the life cycle of the asset	▪ Reliable and accurate relay failure data
▪ Predictive analytics of condition of relay. Relies on a consolidated view of data	▪ To improve analysis and decision making.	▪ Unable to effectively manage the life cycle of the asset	▪ Reliable and accurate relay failure data
▪ Performance indicator for the relay - E.g. % of availability	▪ To measure the performance of the asset against a standard business target (e.g. KPI)	▪ Unable to effectively manage the life cycle of the asset	▪ Performance target endorsed by business

▪ Photograph of relay nameplate and attached to SAP equipment	▪ To improve analysis and decision making ▪ Asset data available form business system for verification and save on site trip	▪ Unable to effectively manage the life cycle of the asset	▪ Clear records of relay nameplates attached to SAP equipment

4.1.5.1 Future improvements

Protection and control equipment has proved reliable as reflected by the low failure rates. However, as detailed earlier, certain electro-mechanical and analogue electronic relay types are exhibiting performance issues, most notably at or near their deemed useful life expectancy. In addition, early generation digital relays are also failing across the network due to issues with their power supply modules.

The asset register for all main secondary equipment including protection and control equipment installed in the JEN electricity network is located in Jemena SAP (JSAP). As part of this sub-asset class strategy review, an audit of the JSAP Equipment Database was conducted for all protection and control equipment and sub-asset information was updated as required.

In order to better manage the relay population, a relatively simple and unique JSAP material equipment ID is being evaluated for each unique relay model in use on the JEN network.

Prioritisation of relay replacement projects is informed by data on relay defects and failure rates and the useful life of the rest of the secondary plant assets. An effective and efficient defect database is under development to improve the accuracy of this critical input data into the asset class decision making.

Re-engineering of the spares management system for zone substation protection and control relays is being evaluated to reinforce the availability of spares in the event of relay failure.

IEC 61850 is an international standard defining communication protocols for substation Intelligent Electronic Devices (IED's - an increasingly popular term to define zone substation relays) to facilitate interoperability of devices from different vendors. The gradual adoption of IEC 61850 is not just defining a new protocol, but also introducing an abstract model of primary and secondary distribution substation equipment and communication systems. IEC 61850 facilitates substation data gathering as well as remote control. Multiple IED's sharing data commands using IEC 61850 reduces the cost of substation control cabling.

In 2013 JEN approved the JEN PL 1000 IEC 61850 Standard for Power Utility Automation - Strategy and Roadmap to implement IEC 61850 technology to enhance substation automation. Power utilities around the world are adopting IEC 61850 as standard protocol for substation automation due to the numerous benefits the standard enables, namely:

- Interoperability between different vendor IED's;
- Reduced cabling costs;
- Reduced configuration costs;
- Simplified application development;
- Improved condition monitoring;
- Adoption of cheaper, safer, digital instrument transformers; and
- Installation of equipment to facilitate emergent smart grid features.

4.2 DC SUPPLY SYSTEMS

4.2.1 INTRODUCTION

A Direct Current (DC) supply system is pivotal to the safe and reliable operation of zone substations and the connected high voltage distribution network under both normal and abnormal operating conditions. DC supply systems are supported by cost effective planned and unplanned maintenance, replacement and augmentation programs. JEN operates and maintains a total of 30 DC Supply Systems installed across 26 zone substations, 3 customer substations and one switching station.

The battery bank must not be allowed to discharge beyond its rated design capacity as this will invariably compromise the reliable operation of zone substation protection and control equipment. Further, the battery bank cannot be switched out of service without the zone substation being shut down. This is not desirable and procedures are in place for safely replacing faulty battery blocks while the battery bank remains in-service.

The main components of DC supply systems are the battery bank and the charger. DC distribution boards and cables are auxiliary items. The scope of this sub-class asset strategy is limited to the battery banks and chargers only. Further, it excludes any DC Supply Systems installed in JEN owned distribution substations or outdoor equipment (such as ACRs) in AusNet Services' terminal stations.

Two types of batteries are deployed:

- Flooded, or vented lead acid (VLA), type; and
- Sealed, or valve regulated lead acid (VRLA), type

In accordance with AS4044-1992 charger classification criteria, JEN's zone substation chargers are classified as Type 1, which is defined as a battery charger suitable for charging a battery with a load connected in parallel.

Figure 18 – Installed battery banks

SUBSTATION	DESCRIPTION OF BATTERY BANK	YEAR OF MANUFACTURE	MANUFACTURER	TYPE OF BATTERY
AW (Airport West)	240V Battery - X	2017	Century Yuasa	VRLA
	240V Battery - Y	2017	Century Yuasa	VRLA
BD (Broadmeadows)	240V Control Battery	2008	Hoppecke	Flooded
	50V Control Battery	2008	Hoppecke	Flooded
	50V Communications Battery	2003	Hoppecke	Flooded
BMS (Broadmeadows South)	110V Battery - X	2015	Century Yuasa	VRLA
	110V Battery - Y	2015	Century Yuasa	VRLA
BY (Braybrook)	110V Control Battery	2004	Battery Energy	Flooded
	24V Communications Battery	2004	Battery Energy	Flooded
	50V Communications Battery	2006	Hoppecke	Flooded
CN (Coburg North)	240V Control Battery	2006	Hoppecke	Flooded
	24V Communications Battery	2007	Hoppecke	Flooded
	50V Control Battery	2007	Hoppecke	Flooded
	240V Battery Bank - Spare	2012	Hoppecke	Flooded
COO (Coolaroo)	110V Control Battery	2006	Hoppecke	Flooded

SUBSTATION	DESCRIPTION OF BATTERY BANK	YEAR OF MANUFACTURE	MANUFACTURER	TYPE OF BATTERY
	50V Control Battery	2006	Hoppecke	Flooded
	50V Communications Battery	2012	Hoppecke	Flooded
CS (Coburg South)	240V Control Battery	2004	Battery Energy	Flooded
	24V Communications Battery	2004	Battery Energy	Flooded
	50V Control Battery	2006	Hoppecke	Flooded
EP (East Preston)	240V Control Battery	2017	Hoppecke	Flooded
	24V Communications Battery	2017	Hoppecke	Flooded
	50V Control Battery	2017	Hoppecke	Flooded
EPN (East Preston New)	110V Battery - X	2015	Century Yuasa	VRLA
	110V Battery - Y	2015	Century Yuasa	VRLA
ES (Essendon)	240V Battery - X	2019	Century Yuasa	VRLA
	240V Battery - Y	2019	Century Yuasa	VRLA
FE (Footscray East)	240V Control Battery	2002	Hoppecke	Flooded
	24V Communications Battery	2017	Hoppecke	Flooded
	50V Control Battery	2002	Hoppecke	Flooded
FF (Fairfield)	36V Control Battery	2004	First Power	VRLA
	48V Control Battery	2013	Vision	VRLA
	110V Control Battery	2007	First Power	VRLA
FT (Flemington)	110V Battery - X	2018	Century Yuasa	VRLA
	110V Battery - Y	2018	Century Yuasa	VRLA
FW (Footscray West)	240V Control Battery	2006	Hoppecke	Flooded
	24V Communications Battery	2012	Hoppecke	Flooded
	50V Control Battery	2006	Hoppecke	Flooded
HB (Heidelberg)	110V Control Battery	2011	Yuasa	VRLA
MAT (Melbourne Airport)	110V Battery - X	2016	Century Yuasa	VRLA
	110V Battery - Y	2016	Century Yuasa	VRLA
NEI (Nilsen Electrical Industries)	120V Battery	2008	Hoppecke	Flooded
	24V Battery	2008	Hoppecke	Flooded
NH (North Heidelberg)	240V Control Battery	2002	Hoppecke	Flooded
	24V Communications Battery	2002	Hoppecke	Flooded
	50V Control Battery	2002	Hoppecke	Flooded
NS (North Essendon)	110V Battery - X	2017	Century Yuasa	VRLA
	110V Battery - Y	2017	Century Yuasa	VRLA
NT (Newport)	240V Control Battery	2004	Battery Energy	Flooded
	50V Control Battery	2004	Battery Energy	Flooded
PTN (Preston)	110V Battery - X	2019	Century Yuasa	VRLA
	110V Battery - Y	2019	Century Yuasa	VRLA
PV (Pascoe Vale)	110V Control Battery	2011	Yuasa	VRLA
	240V Battery - Spare	2016	Century Yuasa	VRLA
SBY (Sunbury)	110V Battery - X	2018	Century Yuasa	VRLA
	110V Battery - Y	2018	Century Yuasa	VRLA
SHM (Sydenham)	110V Control Battery	2007	Hoppecke	Flooded
	50V Control Battery	2007	Hoppecke	Flooded
	50V Communications Battery	2007	Hoppecke	Flooded
	120V Control Battery	2016	Century Yuasa	VRLA
	50V Communications Battery	2016	Century Yuasa	VRLA

SUBSTATION	DESCRIPTION OF BATTERY BANK	YEAR OF MANUFACTURE	MANUFACTURER	TYPE OF BATTERY
SSS (Somerton Switching Station)	50V SCADA Battery	2016	Century Yuasa	VRLA
ST (Somerton)	250V Control Battery	2008	Hoppecke	Flooded
	50V Control Battery	2008	Hoppecke	Flooded
	50V Communications Battery	2008	Hoppecke	Flooded
TH (Tottenham)	240V Control Battery	2008	Hoppecke	Flooded
	50V Control Battery	2008	Hoppecke	Flooded
	50V Communications Battery	2008	Hoppecke	Flooded
TMA (Tullamarine Airport)	110V Battery - X	2015	Century Yuasa	VRLA
	110V Battery - Y	2015	Century Yuasa	VRLA
VCO (Visy Board)	120V Control Battery	2008	Hoppecke	Flooded
	24V Clean Battery	2008	Hoppecke	Flooded
	24V Dirty Battery	2008	Hoppecke	Flooded
YVE (Yarraville)	110V Battery - X	2013	Yuasa	VRLA
	110V Battery - Y	2013	Yuasa	VRLA

Figure 19 – Installed battery chargers

SUBSTATION	DESCRIPTION OF CHARGER	YEAR OF MANUFACTURE	MANUFACTURER
AW (Airport West)	240V Battery Charger - X	2017	Century Yuasa
	240V Battery Charger - Y	2017	Century Yuasa
BD (Broadmeadows)	240V Control Battery Charger	1992	Brodribb
	50V Control Battery Charger	2003	Brodribb
	50V Communications Battery Charger	2003	Brodribb
BMS (Broadmeadows South)	110V Battery Charger - X	2015	Century Yuasa
	110V Battery Charger - Y	2015	Century Yuasa
BY (Braybrook)	110V Control Battery Charger	1999	Brodribb
	24V Communications Battery Charger	1999	Brodribb
	50V Communications Battery Charger	2006	Brodribb
CN (Coburg North)	240V Control Battery Charger	2003	Brodribb
	24V Communications Battery Charger	1980	Westinghouse
	50V Control Battery Charger	1992	Brodribb
	240V Battery Charger Bank - Spare	2012	Brodribb
COO (Coolaroo)	110V Control Battery Charger	2006	Amp Control
	50V Control Battery Charger	2006	Amp Control
	50V Communications Battery Charger	2006	Amp Control
CS (Coburg South)	240V Control Battery Charger	2003	Brodribb

SUBSTATION	DESCRIPTION OF CHARGER	YEAR OF MANUFACTURE	MANUFACTURER
	24V Communications Battery Charger	2016	Century Yuasa
	50V Control Battery Charger	2005	Brodribb
EP (East Preston)	240V Control Battery Charger	2016	Century Yuasa
	24V Communications Battery Charger	2003	Brodribb
	50V Control Battery Charger	2003	Brodribb
EPN (East Preston New)	110V Battery Charger - X	2015	Century Yuasa
	110V Battery Charger - Y	2015	Century Yuasa
ES (Essendon)	240V Battery Charger - X	2019	Century Yuasa
	240V Battery Charger - Y	2019	Century Yuasa
FE (Footscray East)	240V Control Battery Charger	2006	Brodribb
	24V Communications Battery Charger	2016	Century Yuasa
	50V Control Battery Charger	2003	Brodribb
FF (Fairfield)	36V Control Battery Charger	2004	Chloride Power Protection
	48V Control Battery Charger	2003	Chloride Power Protection
	110V Control Battery Charger	2007	Chloride Power Protection
FT (Flemington)	110V Battery Charger - X	2018	Century Yuasa
	110V Battery Charger - Y	2018	Century Yuasa
FW (Footscray West)	240V Control Battery Charger	2006	Brodribb
	24V Communications Battery Charger	2006	Brodribb
	50V Control Battery Charger	2006	Brodribb
HB (Heidelberg)	110V Control Battery Charger	2011	Brodribb
MAT (Melbourne Airport)	110V Battery Charger - X	2016	Century Yuasa
	110V Battery Charger - Y	2016	Century Yuasa
NEI (Nilsen Electrical Industries)	120V Battery Charger	1986	Dimtronics
	24V Battery Charger	1986	Dimtronics
NH (North Heidelberg)	240V Control Battery Charger	2007	Brodribb
	24V Communications Battery Charger	2016	Century Yuasa
	50V Control Battery Charger	2016	Century Yuasa
NS (North Essendon)	110V Battery Charger - X	2017	Century Yuasa
	110V Battery Charger - Y	2017	Century Yuasa
NT (Newport)	240V Control Battery Charger	2006	Brodribb
	50V Control Battery Charger	2005	Brodribb

SUBSTATION	DESCRIPTION OF CHARGER	YEAR OF MANUFACTURE	MANUFACTURER
PTN (Preston)	110V Battery Charger - X	2019	Century Yuasa
	110V Battery Charger - Y	2019	Century Yuasa
PV (Pascoe Vale)	110V Control Battery Charger	2011	Brodribb
	240V Battery Charger - Spare	2016	Century Yuasa
SBY (Sunbury)	110V Battery Charger - X	2018	Century Yuasa
	110V Battery Charger - Y	2018	Century Yuasa
SHM (Sydenham)	110V Control Battery Charger	2007	Brodribb
	50V Control Battery Charger	2007	Brodribb
	50V Communications Battery Charger	2007	Brodribb
SSS (Somerton Switching Station)	120V Control Battery Charger	2001	Amp Control
	50V Communications Battery Charger	2001	Amp Control
	50V SCADA Battery Charger	2001	Amp Control
ST (Somerton)	250V Control Battery Charger	2008	Brodribb
	50V Control Battery Charger	2008	Brodribb
	50V Communications Battery Charger	2008	Brodribb
TH (Tottenham)	240V Control Battery Charger	2008	Brodribb
	50V Control Battery Charger	2008	Brodribb
	50V Communications Battery Charger	2003	Brodribb
TMA (Tullamarine Airport)	110V Battery Charger - X	2015	Century Yuasa
	110V Battery Charger - Y	2015	Century Yuasa
VCO (Visy Board)	120V Control Battery Charger	1986	Dimtronics
	24V Clean Battery Charger	1986	Dimtronics
	24V Dirty Battery Charger	1986	Dimtronics
YVE (Yarraville)	110V Battery Charger - X	2013	Century Yuasa
	110V Battery Charger - Y	2013	Century Yuasa

4.2.2 RISK

4.2.2.1 Criticality

> *The most critical component of a protection, control, and monitoring system is the auxiliary DC control power system. Failure of the DC control power can render fault detection devices unable to detect faults, breakers unable to trip for faults, local and remote indication to become inoperable, etc.*
>
> *Auxiliary DC control power system design for substations*, 2007, Institute of Electrical and Electronics Engineers

Asset criticality assessment was conducted at the sub-asset class level per the Asset Criticality Assessment Procedure (JEM AM PR 0016). Results of this assessment are provided at Appendix A - Asset Criticality Assessment Worksheet.

The DC Supply System sub-asset class has an asset criticality score of AC4 (High) due to operational and health and safety consequences associated with failure. This sub-asset class has a high criticality, determined by its:

- High strategic impact on customer supply;
- Damage to assets and risk of injury to people, due to network faults not being isolated (as a result of inability to automatically trip high voltage circuit breakers); and
- Potential health and environmental impact issues resulting from battery rupture and associated resulting acid spill.

DC supply system's criticality (importance) is further highlighted on account of:

- Regulatory and compliance requirements. The Electricity Safety (Network Assets) Regulations 1999 stipulates that all network faults be isolated automatically and without delay - loss of a DC supply system would mean an inability to isolate faults; and
- JEN reputational damage.

4.2.2.2 Failure modes

High consequence risk realisation to personnel, damage to assets and network reliability can occur from:

- Failure of DC supply system equipment to supply uninterrupted DC supply to protection and control equipment; and
- Mal-operation of DC supply systems (DC supply quality outside acceptable range), which could damage batteries and protection and control equipment.

Contributing factors to failure of flooded VLA batteries are positive grid corrosion, loss of active material, internal shorts, loss of electrolyte and/or plate sulfation.

Contributing factors to failure of VRLA batteries are internal shorts, thermal runaway, dry out, grid corrosion and plate sulfation.

Contributing factors to failure of battery chargers are leaking capacitors, fuses or MCBs of capacitors may also blow or fail (leading to performance degradation, e.g. high AC ripple content in DC output).

4.2.2.3 Current risks

The failure risks, types and consequences for DC supply systems are captured in the Risk Register – Secondary Plant in Jemena Compliance and Risk System (JCARS).

4.2.2.4 Existing controls

Condition Based Risk Management (CBRM) monitors the health and condition of DC supply system equipment. The information is used to develop asset replacement and maintenance plans. CBRM is informed by:

- Inspection and testing;
- Equipment failure trends;
- SCADA alarms;
- Manufacturer MTBF ratings; and
- Industry experience.

Modern DC supply systems provide comprehensive self-monitoring functions and diagnostic features. This equipment is capable of transmitting alarms back to JEN's Co-ordination Centre via SCADA.

4.2.2.5 Future risks

An emerging risk for this asset class is cybersecurity of IP addressable DC supply systems.

4.2.3 PERFORMANCE

4.2.3.1 Requirements

DC supply systems must reliably:

- Provide auxiliary supply for protection, control, metering, SCADA and communication equipment;
- Enable HV circuit breaker closing and opening operations (locally and remotely);
- Enable local indications and alarms;
- Enable control room emergency lighting; and
- Provide auxiliary supply to miscellaneous systems including smoke detectors and security systems.

The DC supply system is designed to support the standing and momentary DC loads of the zone substation. Under normal operating conditions the battery charger supplies the DC loads as well as keeps the battery banks fully charged. In the event of the charger not being able to charge the batteries, e.g. due to failure of the charger or due to interruption of AC supply to the charger, the battery bank must seamlessly support the zone substation DC loads for designated period of time. The nominal design carryover time for JEN zone substation DC supply systems is 8 hours, in accordance with the JEN zone substation Secondary Design Standard (JEN ST 0600).

4.2.3.2 Life expectancy

The design life expectancy of flooded VLA batteries and VRLA batteries is 15 years and 10 years respectively.

The life expectancy assigned to older chargers manufactured before 1985 is 40 years while for the newer chargers manufactured after 1985, life expectancy of 20 years has been assigned.

Life expectancy of batteries is critically dependent on operating temperature and all life expectancies are based on a nominal operating temperature of 25 deg C. In accordance with IEEE Standard 450-2002, batteries follow a Thermal Degradation Curve which is based on a widely accepted rule of thumb for lead-acid battery ageing, that is based on the Arrhenius equation.

Cold temperatures reduce the available capacity whereas higher temperatures greatly reduce service life of batteries. Typical operating temperatures published by battery manufacturers are

- **Flooded VLA cells:** (-) 20 deg C to +40 deg C (recommended 10 deg C to 30 deg C)
- **VRLA Cells:** (-) 15 deg C to +45 deg C (recommended 5 deg C to 30 deg C)

In addition, AC ripple content in the DC output voltage from chargers adversely affects the life of batteries. Overcharging also shortens battery life.

Life expectancy of chargers largely depends on the condition of internal electronic and electrical components.

Replacement decisions of batteries and chargers are based upon product lifetime expectations and in-service monitoring.

4.2.3.3 Age profiles

Age profile notes show that:

- Approximately 20% of the installed batteries and chargers are close to their end of life.

Figure 20 - Age profile of batteries

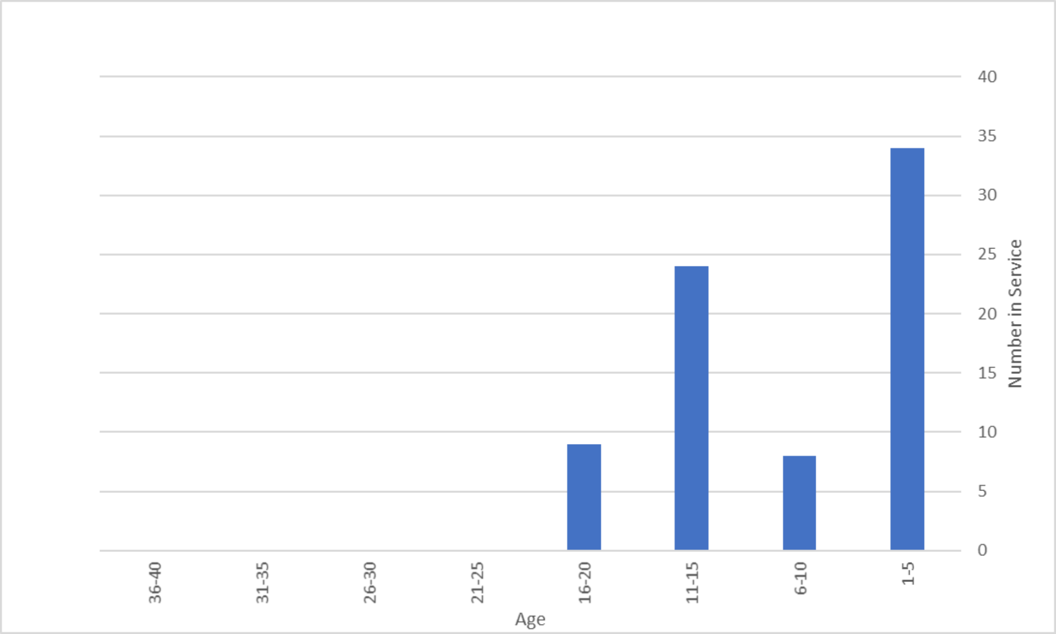
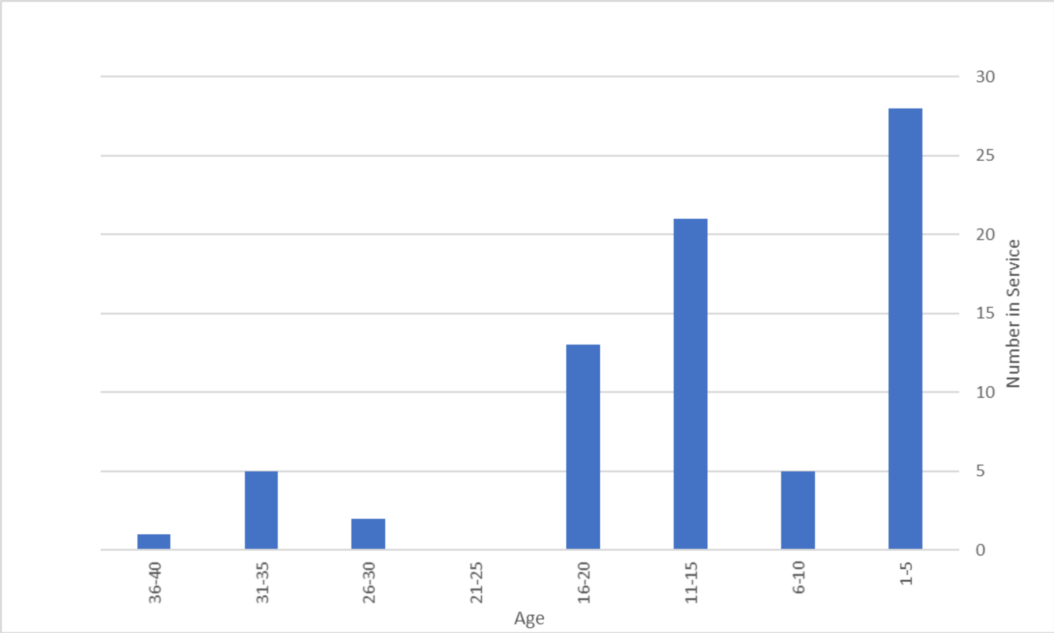


Figure 21 - Age profile of chargers



4.2.3.4 Utilisation

DC supply systems are in-service continuously to supply protection and control equipment as needed.

4.2.3.5 Performance analysis

Based on analysis of asset performance information collated from SAP records and routine maintenance records, the current level of performance of this asset class is:

- Annual failure rate of battery banks and chargers is 3%; and
- Percentage of installed chargers with correct float voltage setting is 97.5%.

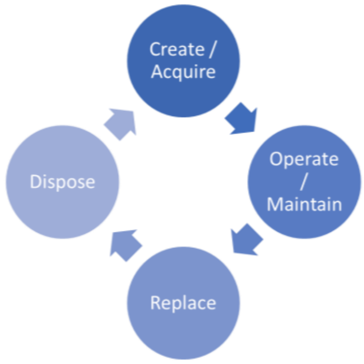
4.2.3.6 Control effectiveness

Existing controls are effective. Spares are held for flooded and VRLA type batteries and chargers. Spares for DC distribution boards shall be procured in FY20/21.

Some chargers have continued to operate satisfactorily beyond their lifetime expectation. Replacement planning is informed by performance factors such as ripple content in output (ripple is an undesirable deterioration of charger output).

4.2.4 LIFE CYCLE MANAGEMENT

4.2.4.1 Creation



Working assets in this sub-asset class are effectively created via acquisition or the deployment of spares. The acquisition triggers for this sub-asset class are:

- New zone substation development works;
- Existing zone substations secondary systems upgrade; and
- Replacement of old assets whose condition has deteriorated and/or which have reached end-of-life

The availability of spare DC supply system equipment is a critical. Spare equipment is required in the event of a defect or failure so as to re-instate full or part functionality of the DC supply system in the shortest possible timeframe.

The objectives of the spares plan are:

Spares management

- minimise outage times of the DC supply system; and
- minimise the cost of holding spares.

Like for like replacement of DC supply system equipment is preferred. This is straight forward with batteries. However there are various types of chargers in service. Consequently, multi-volt chargers are kept as spares which can be used for various DC voltage levels across the network.

Figure 22 - Quantities of DC Supply System spares

Equipment type	Quantities	
	Minimum	Maximum
Flooded lead acid batteries – single bank of 240V DC	1	2
Sealed lead acid batteries – single bank of 240V DC	1	2
Chargers	1	2
DC Distribution Boards (from 2021)		
▪ 240V DC	1	2
▪ 110V DC	1	2
▪ 50V DC	1	2
▪ 24V DC	1	2

Spares are sourced by:

- Purchase from supplier; and
- Freed-up equipment from existing in-service population via a planned replacement.

Batteries

- A spare 240V battery bank of flooded lead acid batteries is installed at Coburg North (CN) zone substation; and
- A spare 240V battery bank of VRLA batteries is installed at Pascoe Vale (PV) zone substation.

In addition, there are some flooded type battery banks which have been rendered spare at PV (2-off 50V and 1-off 130V) & HB (1-off 110V) zone substations after redevelopment of these substations. These batteries are currently kept charged by corresponding spare chargers at these sites.

Chargers

- 2-off multi-voltage battery chargers are held as spare. These are capable of providing emergency supply for 24V, 50V, 110V or 240V applications. These are usually kept at CN and NT zone substation sites.

It is budgeted for 2021 to also establish spares for DC distribution boards of 240V, 110V, 50V and 24V, which shall be kept at the Tullamarine depot.

4.2.4.2 Operation and maintenance

The sub-asset maintenance program involves:

- Preventive maintenance; and
- Reactive maintenance.

Preventative maintenance

The DC supply systems are inspected at 6 monthly and 12 monthly intervals depending on the type of equipment. Flooded batteries require more maintenance than VRLA batteries. Preventive maintenance schedules are created and maintained in SAP. These are based on:

- JEN's work practices;
- Manufacturers recommendations; and
- Australian Standards.

Condition monitoring has been introduced in all new installations of DC Supply Systems beginning with the YVE project in 2013. This involves measurement and trending of the following parameters:

- Battery voltage monitoring;
- Battery impedance monitoring; and
- Charger health monitoring.

For existing DC Supply System installations, battery internal impedance measurement has been performed since 2016 as a condition monitoring tool for battery health assessment for sealed batteries. In addition, battery capacity tests are planned to assess battery condition and battery remaining Ampere-hour (Ah) capacity.

Preventive maintenance of flooded or vented lead acid type batteries is performed on a 6 monthly cycle. The tasks are:

- Visual inspection of the battery bank: checking for any damage to the container, any contamination or signs of leaking;
- Check terminals, connections and cabling;
- Check water levels and top up with distilled water as required (record water usage);
- Measurement of specific gravity of each battery cell;
- Measurement of individual battery cell voltages and bank voltage;
- Impedance measurements of each battery cell;
- Electrolyte specific gravity measurement for one cell from each battery block;
- Check operation of battery exhaust fan; and
- Any additional maintenance tasks as defined by the battery manufacturer.

A full description of the recommended operational conditions and maintenance schedules for flooded batteries is provided in reference document PGI-H-1 Revision A Batteries: Lead-Acid, Pasted Plate, Pure Lead Positive to AS1981.

Routine preventative maintenance of sealed or valve regulated lead acid type batteries is performed on a 6 monthly cycle. The tasks are:

- Visual inspection of the battery bank: checking for any damage to the container, any contamination or signs of leaking;

- Checking of terminals, connections and cabling;
- Measurement of individual battery cell voltages and bank voltage;
- Impedance measurements of each battery cell;
- Confirm readability of all labelling and signage and clean or replace as required; and
- Any additional maintenance task as defined by the battery manufacturer.

VRLA batteries require less maintenance because electrolyte levels remain effectively constant under normal operation as the battery is sealed. As a result, there is no requirement to top-up water levels.

A full description of the recommended operational conditions and maintenance schedules for VRLA batteries are provided in reference document PGI-4155-21: Valve Regulated Lead Acid Sealed Batteries.

Preventative maintenance of battery chargers is performed on a 12 monthly cycle. The tasks are:

- Visual inspection of the battery charger: checking for signs of damage or deterioration;
- Removal of any foreign objects such as excessive dust etc.;
- Visual inspection of wiring, terminals, test links, panel mounted switches, indicating lights, instrumentation etc.;
- Measure DC output voltage to verify that the voltage output of the charger is within acceptable operational limits;
- Confirm operation of charger alarm(s) and check receipt of charger alarm at the Co-ordination Centre via SCADA; and
- Any additional maintenance tasks as defined by the battery charger manufacturer.

In addition, measurement of the charger DC output ripple is performed every 8 years (aligned with the maintenance regime for protection and control equipment in substations).

Reactive maintenance

Reactive maintenance is carried out when faults occur or when defects are identified, resulting in the repair or replacement of assets. Flooded and VRLA type batteries are to be replaced by a similar type. Mixing of VRLA with flooded VLA batteries is not permitted.

DC system equipment faults are typically identified after an investigation arising from an abnormal operation or lack of operation. They may also be identified during routine preventative maintenance or via some form of health condition monitoring with an alarm received in the JEN Control Room via SCADA. Faults must be addressed as a matter of urgency as they represent issues or problems that will or have affected the performance and/or intended operation of critical protection and control equipment.

All equipment faults are fully investigated in an effort to identify and understand the root cause or failure mode.

Assumptions underpinning this sub-asset class' performance are:

- Ageing of all batteries across whole installed base occurs at the same rate; and
- Both hardware and software related failures (e.g. in charger control circuits) have been considered.

Other factors (e.g. battery impedance and voltage measurement, battery capacity measurement etc.) are included, as applicable, in performance measures.

4.2.4.3 Replacement/disposal

There are three possible replacement modes available for this sub-asset:

- Run to failure (reactive);
- Schedule-based replacement (age-based); and
- Condition-based replacement (the most cost effective).

Run to failure means replacement occurs reactively upon failure with no consideration of reliability or age. This mode is unacceptable for high criticality sub-assets like DC supply systems.

Schedule-based replacement, in this context, proposes that DC supply system equipment is replaced at the end of its respective design/product life. It can also mean replacement driven by a large substation refurbishment project.

Condition-based replacement is determined by CBRM data:

- Age of asset;
- Preventative maintenance records;
- Performance of asset; and
- Network Management System monitoring.

As per Australian Standard AS2676.2 Guide to the installation, maintenance, testing and replacement of secondary batteries in buildings Part 2: Sealed cells, 'Physical characteristics, such as age, are often deciding factors for complete battery or individual cell replacement.' A similar suggestion is made in AS2676.1 for flooded batteries. Thus age is a critical factor leading to performance degradation of batteries and is the principal criterion for planning replacement of batteries. However, scheduled replacement of equipment based solely on age is not considered best practice asset management because it results in unnecessary costs.

It is preferable to replace DC supply systems equipment that is not fit for service based on condition or exhibiting symptoms of deterioration. This scenario is considered the most cost effective to meet performance requirements.

However, the life cycle of older type of chargers can be extended to some extent by preventive maintenance (e.g. regular inspection and replacement of critical components like electrolytic capacitors) in so far it is cost-effective.

Continuous monitoring of asset condition and availability is critical to the asset management strategy based on risk related to condition and age. In existing installations, some chargers are equipped with charger failure alarm which is integrated into the SCADA system. For other chargers that do not have this functionality, remote charger fail alarm monitoring feature is progressively being implemented. This will ensure that any charger failures are immediately reported to JEN Control Room via the SCADA network.

Remote access to DC supply systems is also being implemented in newer installations like Yarraville zone substation (YVE). This is being done to remotely collect long-term trending information on the health of batteries (based on voltage and impedance measurements).

Redundancy

While almost all existing installations have single non-redundant systems, redundancy has been mandated in the Secondary Design Standard for all new installations and major redevelopment projects. A redundant system provides not only flexibility in operation and maintenance of systems but also promotes availability of systems.

The existing substation battery banks and battery chargers are not duplicated. These consist of single systems which provide DC supplies ranging from 24V to 240V to support protection & control, SCADA and communication equipment and to operate legacy high voltage switchgear.

In most cases, each system is constructed from standard 6V battery blocks connected in series to achieve the required voltage (for example 18 x 6V for a nominal 110V system). Additionally, in many older zone substations, more than one DC supply system has been installed, with each system being a standalone system and supplying separate loads, for example 50V systems are used for SCADA/communications equipment while 24V systems are used for VF inter-trip equipment. These legacy DC supply systems are being progressively phased out over time, aligned with primary and/or secondary equipment replacements.

At recent zone substation redevelopment projects, e.g. Pascoe Vale (PV), a single 110V DC Supply System has been installed. In addition, DC-DC converters are provided to convert 110V DC to say 50V DC to supply communication loads.

The zone substation Secondary Design Standard (JEN ST 0600) stipulates installing fully duplicated X & Y 110V DC Supply Systems. Starting from the Yarraville (YVE) zone substation project in 2013, ten more projects involving major redevelopment of secondary systems have had duplicated DC Supply System installed. These systems consist of 110V DC VRLA batteries and switch mode rectifier (SMR) chargers.

For replacement of existing DC Supply Systems which have reached end-of-life, the general policy is like-for-like replacement, with due consideration for

- Reducing the overall number of make and model of equipment and standardising on a few makes and models in installed base;

Equipment with improved new technology (e.g. SMR chargers).

Occasionally, a battery experiences stresses that can cause the case to swell, crack, or lose a cap. Batteries in this condition are considered ‘damaged’. These damaged batteries are subject to more stringent regulations than are ‘intact’ batteries, since the damaged batteries pose the risk of hazardous material release.

Current disposal practice is when batteries are retired or replaced, these are packed in accordance with the procedures for packing and transportation as recommended by JEN recycling service provider (current service provider is SIMs Metal Management). The batteries are then transported and disposed by the recycling service provider.

Meanwhile, faulty charger equipment is returned, if appropriate, to the manufacturer for post failure analysis and repaired if economically expedient.

Any faulty equipment that cannot be repaired is disposed of accordingly by a certified recycling company in accordance with Jemena Environment Policy (JEM PO 0397).

Disposal

Ten DC supply systems are nearing their end of life. Recent failures confirm that asset age is a determinant.

The CAPEX replacement timeframe may be adjusted depending on the need to undertake associated works at the specific zone substation such as circuit breaker or transformer replacement , secondary system replacement and zone substation augmentation works.

CAPEX

Figure 23 – DC supply systems forecast CAPEX

Location	Year	Reasons for replacement	Comments
BD	19/20	• Condition of batteries is deteriorating (age ~ 11 years) • One charger failed in 2015	• Replacement cost is included in the BD Relay Replacement Project.

		• Replacement of existing DC supply system by new duplicated X & Y DC system, aligning with BD relay replacement project	• This project is currently underway.
FF	19/20	• Batteries have approached end of life and there have been failures of these sealed batteries. • Replacement of existing DC supply system by new duplicated X & Y DC system, aligning with FF transformer replacement project.	• This project is currently underway.
BY	19/20	• Following are reasons for replacement: o Condition of batteries is deteriorating (age ~ 15 years); o Chargers will be reaching end of life and deteriorating. • Following Battery banks are scheduled for replacement o 110V, 50V and 24V Battery banks. • Following Chargers are scheduled for replacement: o 110V and 24V Battery chargers.	• $572k • BY & CS are funded together under the Batteries & Chargers Replacement Project. • This project is currently underway.
CS	19/20	• Following Battery banks are scheduled for replacement o 240V, 50V and 24V Battery banks • Reason for replacement is condition of batteries is deteriorating (age ~ 15 years).	
FE	20/21	• Batteries have reached end of life • Some battery failure in 2019 • Replacement of existing DC supply system by new duplicated X & Y DC system, aligning with transformer replacement project.	• Replacement cost is included in the FE Switchgear Replacement Project.
FW	20/21	• Batteries are reaching end of life (~ 12 years age) • Some batteries had failed in 2013 • Replacement of existing DC supply system by new duplicated X & Y DC system, aligning with transformer replacement project.	• Replacement cost is included in the FW Switchgear and Relay Replacement Project.
HB	21/22	• Sealed batteries (2 strings, each 110V) approaching end of life.	• Remote battery monitoring will be included to optimise operational expenditure. • Replacement cost is included in the HB

			Transformer Replacement Project.
PV	21/22	• Sealed batteries (2 strings, each 110V) approaching end of life.	• Remote battery monitoring will be included to optimise operational expenditure at PV. • $689k • PV, NT, VCO and Spares are funded together under the Battery & Charger Replacement initiative 21-22.
NT	21/22	• Batteries (240V Control, 50V Control and 50V communication) approaching end of life • 50V Charger approaching end of life.	
VCO	21/22	• Chargers (120V, 24V Dirty and 24V Clean) approaching end of life.	
Spares	21/22	• Spare DC Distribution Boards ○ 240V DC Distribution Board ○ 110V DC Distribution Board ○ 50V DC Distribution Board ○ 24V DC Distribution Board	
SHM	22/23	• Batteries (110V, 50V Control and 50V Communications) approaching end of life.	• $125k
CN	22/23	• Batteries (240V Control, 50V Control and 24V communication) and Chargers reaching end of life • Replacement of existing DC supply system by new duplicated X & Y DC system, aligning with CN relay replacement project.	• Replacement cost is included in the CN Switchgear and Relay Replacement Project.
CS	23/24	• Batteries (240V Control, 50V Control and 24V communication) and Chargers reaching end of life • Replacement of existing DC supply system by new duplicated X & Y DC system, aligning with CS relay replacement project.	• Replacement cost is included in the CS Switchgear and Relay Replacement Project.
ST	23/24	• Batteries (250V Control, 50V Control and 50V communication) approaching end of life .	• $471k • ST and TH are funded together under the Battery & Charger Replacement initiative 22-25.
TH	23/24	• Batteries (240V Control, 50V Control and 50V communication) approaching end of life • 50V Charger approaching end of life.	
NEI	24/25	• Batteries (120V Control, 24V Control batteries) approaching end of life • Replacement of charger.	• $813k • NEI, VCO and YVE are funded together under the Battery & Charger Replacement initiative 22-25.
VCO	24/25	• Batteries (120V Control, 24V Dirty and 24V Clean) approaching end of life.	
YVE	24/25	• Sealed batteries (Duplicated X & Y 110V DC) approaching end of life.	
BMS	25/26	• Sealed batteries (Duplicated X & Y 110V DC) approaching end of life.	• $744k

TMA	25/26	• Sealed batteries (Duplicated X & Y 110V DC) approaching end of life.	• BMS, TMA and EPN are funded together under the Battery & Charger Replacement initiative 22-25.
EPN	25/26	• Sealed batteries (Duplicated X & Y 110V DC) approaching end of life.	

4.2.5 Information

JEN's AMS (Section 1.2 above) provides a hierarchical approach to understanding the information requirement to achieve Jemena's business objectives at the Asset Class. In summary, the combination of Jemena's Business Plan, the individual Asset Business Strategy (ABS) and Asset Class Strategy (ACS) all provide the context to determine the information required to deliver the sub-asset class' business outcomes.

The high-level information requirements to achieve the ACS's business objectives and inform its critical decisions were identified at a facilitated workshop during the ACS definition process. The DC supply systems sub-asset class identified two business objectives together with the business information required to support these objectives set out in Figure 24. Current and future information requirements to inform value-add decision making are at Figure 25. A proposed improvement future business information need is at Figure 26.

Figure 24 - DC supply system equipment business objectives and information requirements

Business objective	JEN information sources	Externally sourced data
To minimise the damage to network assets, risk of injury to personnel due to network faults and maintain reliability of electricity supply to customers.	• DrawBridge • SAP • RESIS • SCADA • ECMS	• SAI Global – AS/IEC Standards • Manufacturer's technical documents • Industry Fault History • Alerts from manufacturer

Figure 25 - DC supply system equipment critical decision business information requirements

Critical business decision	Current information usage	Future information requirement	Value to asset class (High, Medium, Low with justification)
Asset Creation	▪ Specification and tender responses ▪ Asset register in SAP ▪ Asset information in RESIS		High - Regulatory obligation to maintain network continuity and security of supply and safety

When to maintain and replace DC Supply System equipment.	Asset register in SAP with details of each assets ▪ Functional Location ▪ Manufacturer ▪ Model ▪ Equipment Description ▪ Installation Date ▪ Location: zone substation Asset Defect Register ▪ Event description ▪ Equipment Model ▪ Date and time of defect ▪ SAP Notification Number DrawBridge ▪ DC Supply system related drawings Performance History ▪ Daily Situation Report (DSR) ▪ Incident Investigation Reports (ECMS)	▪ Require published figures of DC Supply System failures – worldwide ▪ Require asset operational and maintenance records to be made available in SAP ▪ Unit cost of DC Supply System replacement.	High - Regulatory obligation to maintain network continuity and security of supply and safety
Respond to DC Supply System defects to restore equipment operationally. Perform corrective maintenance.	▪ Alert via NOC or Daily Situation Report ▪ Asset Defect Register	▪ All defect data to be collected and stored within SAP to enable effective root cause and performance analysis	High - Regulatory obligation to maintain network continuity and security of supply and safety

Figure 26 - Information initiatives to support business information requirements

Information initiative	Use case description	Asset class risk in not completing	Data quality requirement
Require published figures of DC Supply System failures – worldwide.	To improve analysis and decision making.	Unable to effectively manage the life cycle of the asset.	Reliable and accurate DC Supply System failure data for similar type of equipment.
Predictive analytics of condition of DC Supply System. Relies on a	To improve analysis and decision making.	Unable to effectively manage the life cycle of the asset.	Reliable and accurate DC Supply System failure data for similar type of equipment.

consolidated view of data.			
Photograph of DC Supply System equipment nameplate and attached to SAP records.	To improve analysis and decision making. Asset data available form business system for verification and save on site trip.	Unable to effectively manage the life cycle of the asset.	Clear records of DC Supply System equipment nameplates attached to SAP records.
Unit cost of DC Supply System equipment replacement.	To better budget CAPEX forecast for future replacement.	Inaccurate CAPEX forecast leading to insufficient/over budget.	Accurate unit cost of DC Supply System equipment replacement by scheme.

4.2.5.1 Future improvements

Under consideration are:

- Feasibility of introducing battery capacity testing (to determine when they decline below 80% rated capacity, triggering replacement);
- Feasibility of remote monitoring of flooded VLA batteries; and
- Data obtained from various sources is manually entered into a spreadsheet. Explore options to automate this process to facilitate thorough trend analysis for routine maintenance records currently kept as hardcopy by field personnel.

4.3 COMMUNICATIONS CABLING

4.3.1 INTRODUCTION

JEN's copper and fibre optic network infrastructure is used by SCADA communications, protection and data signalling circuits.

This sub-asset class strategy aims to maximise the return on investment through:

- Optimisation of augmentation/investment costs through strategic sourcing and effective evaluation of options; and
- Optimisation of maintenance costs through an effective maintenance plan.

This sub-asset class strategy is based on key information about the asset (including risk, performance, life cycle management and expenditure estimates).

JEN has 11 remaining copper cables which have exceeded their end of life expectancy of 50 years. These assets will be decommissioned systematically, with related protection upgrade projects and new fibre put in its place, if not already available.

There are around 300 fibre optic cables in the JEN. The first few installations were in 2001, followed by many in 2002 and onwards, hence the oldest cables are only 19 years old. The asset life of a fibre optic cable is around 50 years.

4.3.2 RISK

4.3.2.1 Criticality

Asset criticality assessment was conducted by following the Asset Criticality Assessment Procedure (JEM AM PR 0016). Results of this assessment are presented in Appendix A.

Communications cable sub asset class has an asset criticality score of AC3 and the criticality of Significant due to the fact that the cables provide highly critical communications services to JEN zone substations.

4.3.2.2 Failure Modes

The failure risks, types and consequences is assessed based on communications cable failure caused predominantly by unexpected cable cuts for fibre optic cable and age related deterioration of copper supervisory cable.

4.3.2.3 Current Risks

JEN communication cable failure risks, types and consequences are captured in Risk Register – Secondary Plant in Jemena Compliance and Risk System (JCARS).

The risk of communications cable failure is considered to be 'Significant' based on current Jemena Risk Assessment standard. The major risk associated with this Sub Asset Class failure has been identified as failure of pilot wired protection schemes and losing redundancy of 66 kV line protection schemes. The likelihood and consequence of this type of failure occurrence are Possible and Severe respectively.

4.3.2.4 Existing Controls

Communication links for critical services like JEN 66 kV line protection schemes are established over the communication cables. To prevent single point of failure, JEN communications cable network has been constructed with redundancy to each communication site, that means communication cables accessing a JEN zone substation or other communication sites with dual cable routes via diverse cable paths.

4.3.2.5 Future Risks

The salient risk of this sub-asset class is the age related deterioration of the copper supervisory cable which can fail at any time. Retirement of the copper supervisory cabling has been aligned with future upgrades of pilot wired protection relays.

4.3.3 PERFORMANCE

4.3.3.1 Requirements

The HV protection sub-code referred to in Clause 100.4 of the Victorian electricity system code requires continuous operation of communications cabling. Accordingly communications cabling is designed to JEN's X & Y redundancy specification and JEN's Communications Design & Installation Standard (JEN PR 0029). Single mode and multi-mode fibre optic cables must meet AS/ACIF S009:2013 Installation requirements for customer cabling.

If there is a fault at an X or Y redundancy fibre, the aim is to avoid 'single contingency' for >9hrs. However, depending on the nature of the fault, it may take longer for JEN contractors to mobilise. In these instances the fault must be rectified within 24 hours.

4.3.3.2 Life expectancy

The life expectancy for communication cables is 50 years.

- For copper this life expectancy is supported by empirical evidence
- For fibre optic cable the manufacturer's advice is relied upon.

Copper cable is more prone than fibre optic cable to factors impacting life expectancy, namely:

- Water ingress for underground cables;
- Heat and weather conditions for overhead cables; and
- Age related deterioration.

4.3.3.3 Age profiles

The copper supervisory cable have all been in-service in JEN for close or over 50 years. These cables shall be retired when the protection relays and other associated equipment are replaced with more modern equipment using fibre optic cable. The current in-service copper supervisory cables have a total length of about 48 km and were installed between 1943 and 2001.

JEN has installed 300km of fibre optic cable since 2001:

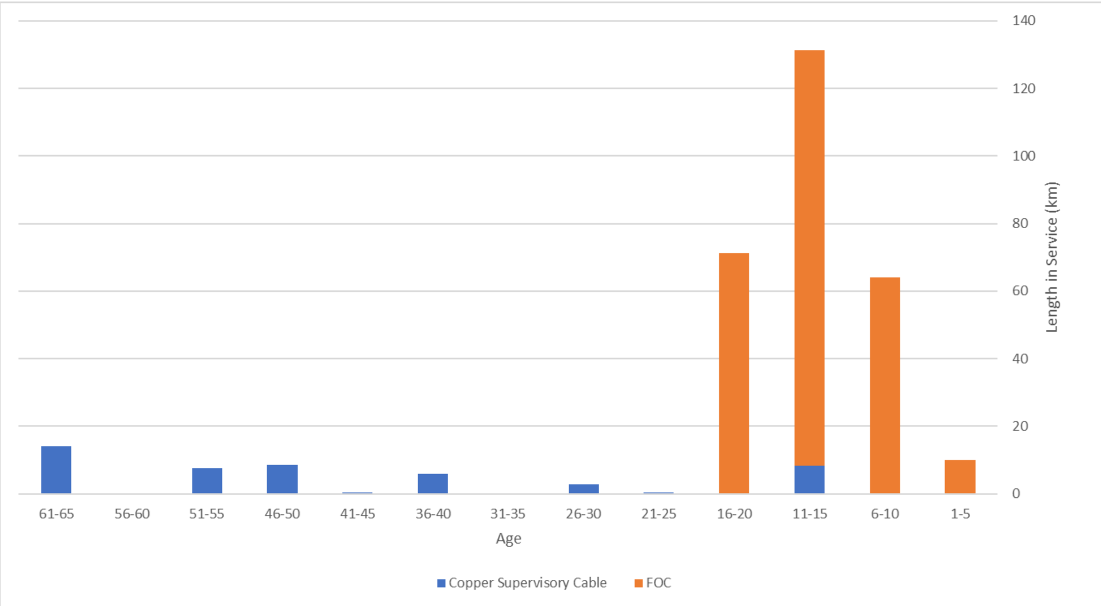
- 125 km was installed between 2001 and 2005;
- 123 km was installed between 2006 and 2010;

- 47 km was installed between 2011 and 2015; and
- 5 km was installed between 2016 and 2018.

Legacy copper supervisory cable was installed prior to 2005:

- 14km was installed pre 1956;
- 7.65km was installed 1961-1965;
- 8.47km was installed 1966-1970;
- 0.43km was installed 1971-1980;
- 5.94km was installed 1976-1980;
- 2.92km was installed 1986-1990;
- 0.46km was installed 1991-1995;
- 0.19km was installed 1996-2000; and
- 8.26km was installed 2001-2005.

Figure 27 – Communications cabling by year installed



4.3.3.4 Utilisation

Communications cabling is in-service continuously to monitor and facilitate control of protection equipment as needed.

4.3.3.5 Performance analysis

Communication cable failures are usually caused by cables being cut. The root cause of the cable cut for underground cables are dig-up, excavation, and building over cables; for overhead cables vehicle collision and sabotage. Traditionally when a cable link fails on overhead systems, predominantly it is due to vehicle collisions. If the root cause of a cable failure or mal-operation is unknown, an investigation is carried out to determine the root cause. Findings from the investigation are analysed with associate network impact figures (e.g. SAIDI SAIFI and MAIFI) due to the failure.

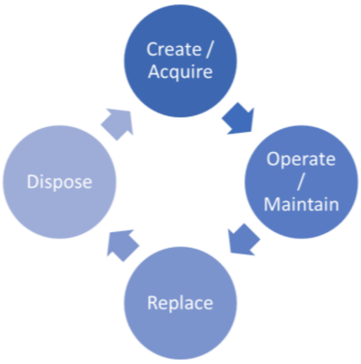
Based on the fault register in SAP and supplied by operation staff, the average of communication cable failure was 2 events every year for the last 6 years.

4.3.3.6 Controls effectiveness

Designing redundancy into the cabling topology is highly effective.

Health and condition monitoring of these assets is employed where this information is available to develop asset replacement and maintenance plan.

4.3.4 LIFE CYCLE MANAGEMENT



4.3.4.1 Creation

No further copper supervisory cabling shall be procured.

Three scenarios trigger the need to acquire and install new fibre optic cable:

- Replacement of copper supervisory cable;
- New installations; and
- Repair existing installation.

Supplier lead time for fibre optic cables can be 6-8 weeks. JEN holds spares stock of:

- 2km of single mode 48-core overhead type fibre optic cable;
- 2km of single mode 48-core underground type fibre optic cable;
- 300m multi-mode fibre optic cable;
- 100 single mode 2-core patch leads of various lengths; and
- 100 multi-mode 2-core patch leads of various lengths.

4.3.4.2 Operation and maintenance

This sub-asset maintenance program involves:

- Preventive maintenance; and
- Reactive maintenance.

Preventative maintenance consists of inspection and testing:

- Cable attachments to poles and accessories are visually inspected annually;
- SAP will be updated to reflect all observations and issues observed during the inspection, using asset inspection procedures and documentation;
- The inspection results and observations will be reported to the Asset Manager in the monthly Asset Maintenance Performance report; and
- Potential cable issues requiring remediation works will be initiated and managed through the Service Order process in SAP.

Reactive maintenance consists of:

- Repair within 24 hours; or
- Replacement (with a spare) within 24 hours.

4.3.4.3 Replacement/disposal

Generally there are three maintenance modes available for this sub-asset life cycle management. The alternative sub-asset replacement modes are:

- Run to failure (reactive);
- Schedule-based replacement (age-based); and
- Condition-based replacement (the most cost effective).

Run to failure means replacement occurs reactively upon failure (irrespective of age or condition). This mode can occur with the copper cabling not yet replaced by fibre optic cable.

Schedule-based replacement, in this context, proposes that cabling is replaced at the end of its respective design/product life. It can also mean replacement driven by a substation refurbishment projects, e.g. protection relay upgrade.

Condition-based replacement is determined by CBRM data:

- Age of asset;
- Preventative maintenance activities and record keeping;
- Performance of asset; and
- Network Management System monitoring.

A dedicated SNMP server is deployed to monitor the operation of the IP equipment connected at both ends of communication cables. Alarms are sent to technical support staff when faults related to both the end equipment and the communication cables occur. Action, in response to the alarms, is taken immediately.

To reiterate, copper supervisory cables in JEN will eventually be replaced with fibre optic cables. Overhead copper supervisory cable will be removed from poles after been retired from service. The removed cable shall be disposed in a safe manner so that they do not represent any risk to the distribution network, staff and the public. It shall be the responsibility of JEN Services and Projects teams to ensure appropriate procedures are followed for the disposal of the removed copper supervisory cable.

The following CAPEX budget options shall be used to cover the cost on the removal of JEN overhead copper supervisory cable from poles:

- Include the tasks of removing the overhead copper supervisory cables which are decommissioned due to the upgrade of protection relays in the scope of works of the protection relay replacement projects;
- Apply for budget to remove the abandoned overhead copper supervisory cables together with any other relevant CAPEX/OPEX projects (e.g. the removal of switch wire projects) to reduce cost; and
- Apply for budget to remove the abandoned overhead copper supervisory cables as independent projects.

JEN underground constructed copper supervisory cable shall be abandoned safely and ensure the abandoned cables are terminated, air-gapped and earthed at the interface between the ground and above ground atmosphere.

Overhead copper supervisory cables 29 (between TTS and PTN), 229 (between PTN and EP/EPN), 496 (between EP and NEI) and 257 (between NEI and NH) will be decommissioned and removed from the poles as part of zone substation North Heidelberg (NH) Secondary Equipment Replacement project in 2021.

The following decommissioned copper supervisory cables will be removed from the poles as detailed:

- Cable 264 (between ES and BY), Cable 266 (between KTS and BY) and Cable 428 (between BY and T/H, FY) will be removed as part of zone substation BY (Braybrook) Replace Aged Relays project in 2021; and
- Cable 328X (between BLTS and FW) will be removed as part of FW Switchgear & Relay Replacement (BAA-RSA-800085) in 2019.

Opportunities will be taken to remove cables 305 (between HB and LP), 321 (between ST and TTS), 192X (between AW and KTS), 194X (between ES and PV), 221 (between AW and SRD) from the poles.

The following fibre optic cable will be constructed in JEN between 2021 and 2025:

- 5km of JEN standard fibre optic cable will be constructed in 2021 as part of zone substation North Heidelberg (NH) Secondary Equipment Replacement project; and
- 8 km of JEN standard fibre optic cable will be constructed in 2021 as required on CAPEX project of JEN FOC Network Optimisation

Decommissioned cabling is disposed of by a certified recycling company in accordance with JEN Copper Supervisory Cable Decommission Strategy (ELE AM PL 0002) and Jemena Environment Policy (JEM PO 0397).

4.3.5 INFORMATION

JEN's AMS (Section 1.2 above) provides a hierarchical approach to understanding the information requirement to achieve Jemena's business objectives at the Asset Class. In summary, the combination of Jemena's Business Plan, the individual Asset Business Strategy (ABS) and Asset Class Strategy (ACS) all provide the context to determine the information required to deliver the sub-asset class' business outcomes.

The high-level information requirements to achieve the ACS's business objectives and inform its critical decisions were identified at a facilitated workshop during the ACS definition process. The communication cabling sub-asset class identified two business objectives together with the business information required to support these objectives set out in Figure 28. Current and future information requirements to inform value-add decision making are at Figure 29. A proposed improvement future business information need is at Figure 30.

Figure 28 - Communications cabling business objectives and information requirements

Business objective	JEN information sources	Externally sourced data
Maintain safety, availability and reliability of communications cabling	• SAP • DrawBridge • SCADA servers • ECMS.	• SAI Global; • Manufacture – product information; • Industry fault history – Distribution Business.

Figure 29: Communications cabling critical decisions business information requirements

Critical business decision	**Current information usage**	**Future information requirement**	**Value to sub-asset class (High, Medium, Low with justification)**
Communications Cable - Asset Creation	• Specifications and tender responses. • Zone substation Secondary Design Standard. • JEN IEC61850 Network Design Guide. • JEN Communications Design & Installation Standard. • New asset project progress reporting. Completion recorded in SAP. • Asset register in SAP.		High: Critical component for communications system for 66kV link protection schemes.

Maintain functionality of Communications Cable via Inspections, and audits	Asset register SAP, with details of each asset and significant components;
	• Manufacturer
	• Cable type
	• Construction year
	• Basic specification
	  ○ Unit transmission loss
	  ○ Bending radius
	• Fibre Optic Cable path
	• Overhead or underground
	Performance history:
	• Plant defect and fault reports
	DrawBridge – design drawings/layouts.
	SAP notifications and work orders activities performed and components replaced.
	Details of work completed recorded in SAP
		Migrate Condition & Performance reports/data into SAP to improve analysis and decision making.	High: Critical component for communications system for 66kV link protection schemes.

Maintain functionality of Communications Cable via Preventative Maintenance	• Preventive maintenance tasks, schedules, progress and measurements as applicable in SAP. • Scheduled task description, timing and completion recorded in SAP. • Manufacturers maintenance manuals. • SAP notifications and work orders activities performed and components replaced.	Details of work completed recorded in SAP. All maintenance reports to be attached to the relevant SAP equipment. Update asset data in SAP for missing data.	High: Critical component for communications system for 66kV link protection schemes.

Maintain functionality of Communications Cable via Condition Monitoring	Communications Cable Functional Location
	• Installation date
	• Cable type
	• Technology
	• Defect register
	  ○ Events
	  ○ Cable section
	  ○ Date time
	  ○ Notification number
	Asset operational condition reporting.
		Migrate Condition & Performance reports/data into SAP to improve analysis and decision making.	High: Critical component for communications system for 66kV link protection schemes.

Respond to Communications Cable defects / faults to restore equipment operationally. Perform corrective maintenance.	Alerted via network management system. Completed corrective maintenance work recorded briefly in SAP. Performance history: • Plant fault or defect reports.	Asset failure details and investigation reports are available. Update asset data, in SAP for missing data.	High: Critical component for communications system for 66kV link protection schemes.

Figure 30 - Information initiatives to support business information requirements

Information initiative	Use case description	Risk in not completing	Data quality requirement
Migrate Condition & Performance reports/data into SAP. Update asset data in SAP for missing data.	• To improve analysis and decision making. • Asset data available from business systems saving on site trips.	Poor efficiency in accessing asset data and possible risk of maintenance inefficiencies.	Asset Data as per SAP requirements.

4.3.5.1 Future improvements

Evaluation of cable management software to visualise cable run light/dark cores to optimise utilisation of fibre optic cables is in its initial stages. This kind of optimisation platform has the potential to deliver co-ordination benefits (e.g. with Ausnet) and commercial benefits (e.g. leasing bandwidth to VicRail).

4.4 MULTIPLEXER SYSTEMS

4.4.1 INTRODUCTION

This sub-asset class strategy aims to maximise the return on investment through:

- Optimisation of augmentation/investment costs through strategic sourcing and effective evaluation of options; and
- Optimisation of maintenance costs through an effective maintenance plan.

This sub-asset class strategy is based on key information about the asset (including risk, performance, life cycle management and expenditure estimates).

JEN's multiplexing is a complicated system using ring topology with X & Y redundant loops for each line protection scheme. Multiplexing is used to increase the utilisation of the communications cable assets, as one cable core can be used to carry many circuits.

JEN has 83 Nokia Multiplexers and 96 VF equipment. The VF equipment are legacy systems and are being superseded with multiplexers, hence no more VF installations will take place. The first few multiplexer installations were in 2001, followed by many in 2002 and onwards, hence the oldest devices are 19 years old. The asset life of a multiplexer is around 15 years, hence replacement plans have been considered for the upcoming EDPR period.

4.4.2 RISK

4.4.2.1 Criticality

Asset criticality assessment was conducted by following the Asset Criticality Assessment Procedure (JEM AM PR 0016). Results of this assessment are presented in Appendix A.

The multiplexer sub-asset class has an asset criticality score of AC3 and the criticality rating of Significant because the multiplexers provide communication services over fibre optic cable to critical 66 kV line protection schemes and major SCADA traffic to and from JEN zone substations.

Because of their criticality, dual X & Y multiplexer systems are installed at each zone substations for redundancy.

4.4.2.2 Failure modes

Multiplexer faults are typically as a result of either some abnormal operation or lack of operation. Failure modes are characterised by a faulty power supply, processor module or uplink module.

4.4.2.3 Current risks

JEN multiplexer failure risks, types and consequences are captured in Risk Register – Secondary Plant in Jemena Compliance and Risk System (JCARS).

The risk of multiplexer failure is considered to be 'Significant' based on current Jemena Risk Assessment standard. The major risk associated with multiplexer failure has been identified as losing redundancy of 66 kV line protection schemes.

4.4.2.4 Existing controls

Existing controls for JEN multiplexers are essentially those maintenance tasks registered on SAP, together with effective systematic equipment performance monitoring, spare management and initiation of replacement projects determined to in terms of the operation conditions and the technical life cycle of this Sub Asset Class.

JEN multiplexers are monitored with a dedicated Commtel Network Management System (CNMS-NG). Technical support staff in duty will be informed immediately after multiplexer performance and fault events occur.

Contingency planning stipulates immediate response to system alarms by field crews to resolve the issue. If required, the faulty equipment will be replaced with spares from stock.

4.4.2.5 Future risks

Cybersecurity. A breach could result in:

- A backdoor into JEN's network; and
- Loss of functionality, visibility and control.

4.4.3 PERFORMANCE

4.4.3.1 Requirements

Multiplexers are expected to operate continuously providing communications capacity up to their rated values to meet the needs of protection control and SCADA services.

Multiplexers are selected and installed in accordance with JEN's Communications Design & Installation Standard (JEN PR 0029).

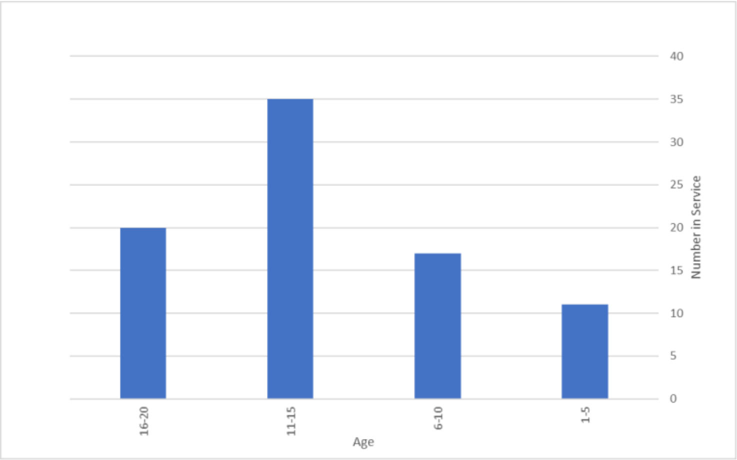
4.4.3.2 Life expectancy

Multiplexer design/product life is 20 years, similar to that of modern protection relays.

4.4.3.3 Age profiles

The total number of Multiplexers currently in-service is 83.

Figure 31 – Multiplexers by in-service years



4.4.3.4 Utilisation

Multiplexers are continuously in-service so as to facilitate the monitoring and control of electricity network equipment.

4.4.3.5 Performance analysis

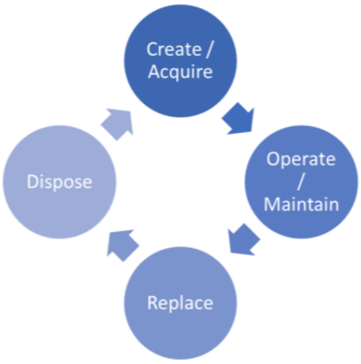
When a multiplexer fails or mal-operates an investigation is carried out to determine the root cause. Findings from the investigation are analysed with associate network impact figures (e.g. SAIDI, SAIFI and MAIFI) due to the failure.

Based on the fault register in SAP, the average multiplexer failure is 2 every year for the last 6 years.

4.4.3.6 Controls effectiveness

CNMS is stable and field response is effective.

4.4.4 LIFE CYCLE MANAGEMENT



4.4.4.1 Creation

Two scenarios trigger the need to acquire and establish new multiplexer channels:

- To replace a multiplexer that is beyond economic repair; or
- The building, or refurbishment of a new substation/scheme.

Multiplexers by Avara are JEN’s standard model. Supplier lead time is 6-8 weeks. JEN keeps two in stock as spares.

4.4.4.2 Operation and maintenance

This sub-asset maintenance program involves:

- Preventive maintenance; and
- Reactive maintenance.

Preventative maintenance consists of monitoring, inspection and testing:

- SAP is updated to reflect all observations and issues observed during the inspections, using asset inspection procedures and documentation;
- The results of the inspection and observations are reported to the Asset Manager in the monthly Asset Maintenance Performance report; and
- Any potential issues requiring remediation works are initiated and managed through the Service Order process in SAP.

Reactive maintenance consists of:

- Repair within 24 hours; or
- Replacement (with a spare) within 24 hours.

4.4.4.3 Replacement/disposal

Generally there are three maintenance modes available for this sub-asset life cycle management. The alternative sub-asset replacement modes are:

- Run to failure (reactive);
- Schedule-based replacement (age-based); and
- Condition-based replacement (the most cost effective).

Run to failure means replacement occurs reactively upon failure (irrespective of age or condition).

Schedule-based replacement, in this context, proposes that each multiplexer is replaced at the end of its respective design/product life. It can also mean replacement driven by a substation refurbishment projects, e.g. protection relay upgrade.

Condition-based replacement is determined by CBRM data:

- Age of asset;
- Preventative maintenance activities and record keeping;
- Performance of asset; and
- Network Management System monitoring.

Decommissioned equipment is disposed of by a certified recycling company in accordance with Jemena Environment Policy (JEM PO 0397).

Figure 32: Forecast capital expenditure

Location	Year	Reasons for replacement	Comments
CN	2022	• Two (2) new multiplexer systems are required to meet the communications channels requirement for the IEC61850 implementation at CN.	• Carried out as part of the Mitigate Risks Associated with Deteriorated Relays - CN project. • Total CAPEX is $80k.
CS	2023	• Two (2) new multiplexer systems are required to meet the communications channels requirement for the IEC61850 implementation at CS.	• Carried out as part of the Mitigate Risks Associated with Deteriorated Relays - CS project. • Total CAPEX is $80k.
NH / NEI	2024	• Six (2) and two (2) of the multiplexer systems deployed at TTS and NH have	• Carried out as part of the Mitigate Risks Associated

Location	Year	Reasons for replacement	Comments
		been in-service since 2001 and 2005 respectively. The systems shall be replaced due to the deterioration of the electronic components of the systems.	with Deteriorated Relays – NH / NEI project. • Total CAPEX is $160k.
NS	2025	• The 2 multiplexer systems at NS has been in-service since 2006 and shall be replaced duo to the deterioration of the electronic components of the systems.	• Carried out as part of the Mitigate Risks Associated with Deteriorated Relays - NS project. • Total CAPEX is $80k.
BTS & KTS (7 Mux & 3 SW)	2025	• Nearing end of design/product life.	• A standalone project combination of multiplexers and switches. • Total CAPEX is $330k.

4.4.5 Information

JEN's AMS (Section 1.2 above) provides a hierarchical approach to understanding the information requirement to achieve Jemena's business objectives at the Asset Class. In summary, the combination of Jemena's Business Plan, the individual Asset Business Strategy (ABS) and Asset Class Strategy (ACS) all provide the context to determine the information required to deliver the sub-asset class' business outcomes.

The high-level information requirements to achieve the ACS's business objectives and inform its critical decisions were identified at a facilitated workshop during the ACS definition process. The multiplexer sub-asset class identified two business objectives together with the business information required to support these objectives set out in Figure 33. Current and future information requirements to inform value-add decision making are at Figure 34. A proposed improvement future business information need is at Figure 35.

Figure 33 - Multiplexer business objectives and information requirements

Business Objective	JEN information sources	Externally sourced data
Maintain safety, availability and reliability of the multiplexers	▪ SAP ▪ DrawBridge ▪ SCADA servers ▪ ECMS	▪ SAI Global ▪ Manufacture – product information ▪ Industry fault history – Distribution Business

Figure 34 - Multiplexer critical decisions business information requirements

Critical business decision	Current information usage	Future information requirement	Value to sub-asset class (High, Medium, Low with justification)
Multiplexer - Asset Creation	• Specifications and tender responses. • Zone substation Secondary Design Standard. • JEN IEC61850 Network Design Guide. • JEN Communications Design & Installation Standard. • New asset project progress reporting. Completion recorded in SAP. • Asset register in SAP.		High: Critical component to provider communications circuits for 66kV line protection schemes.

Maintain functionality of Multiplexer via Inspections, and audits	Asset register SAP, with details of each asset and significant components;
	• Manufacturer
	• Type
	• Equipment description
	• Construction year
	• Basic specification
	  ○ Interface type
	  ○ System capability
	• Location: zone substation name
	• Address
	
	Condition Monitoring
	Maintenance reports
	Test reports
	
	Performance history:
	• Plant defect and fault reports
	
	DrawBridge – design drawings/layouts.
	
	SAP notifications and work orders activities performed and components replaced.
	
	Details of work completed recorded in SAP.
		Migrate Condition & Performance reports/data into SAP to improve analysis and decision making.	High: Critical component to provider communications circuits for 66kV line protection schemes.

Maintain functionality of Multiplexer via	• Preventive maintenance tasks, schedules, progress and measurements as applicable in SAP.	Details of work completed recorded in SAP.	High: Critical component to provider communications circuits for 66kV

Critical business decision	Current information usage	Future information requirement	Value to sub-asset class (High, Medium, Low with justification)
Preventative Maintenance	• Scheduled task description, timing and completion recorded in SAP. • Manufacturers maintenance manuals. • SAP notifications and work orders activities performed and components replaced.	All maintenance reports to be attached to the relevant SAP equipment. Update asset data in SAP for missing data. Details of spare equipment located in SAP.	line protection schemes.

Maintain functionality of Multiplexer via Condition Monitoring	Multiplexer Functional Location
	• Installation date
	• Model
	• Technology
	• Defect register
	  ○ Events
	  ○ Model
	  ○ Date time
	  ○ Notification number
	Asset operational condition reporting.
		Migrate Condition & Performance reports/data into SAP to improve analysis and decision making.	High: Critical component to provider communications circuits for 66kV line protection schemes.

Respond to Multiplexer defects / faults to restore equipment operationally. Perform corrective maintenance.	Alerted via network management system. Completed corrective maintenance work recorded briefly in SAP. Performance history: • Plant fault or defect reports.	Asset failure details and investigation reports are available. Update asset data, including spares, in SAP for missing data.	High: Critical component to provider communications circuits for 66kV line protection schemes.

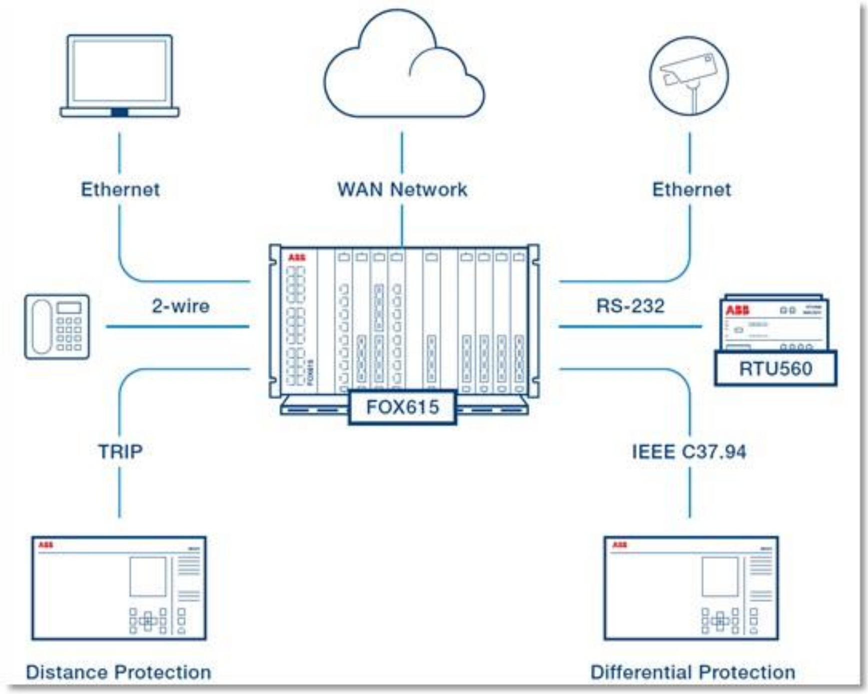
Figure 35 - Information initiatives to support business information requirements

Information initiative	Use case description	Asset class risk in not completing	Data quality requirement
Migrate Condition & Performance reports/data into SAP. Update asset data in SAP for missing data.	• To improve analysis and decision making. • Asset data available from business systems saving on site trips.	Poor efficiency in accessing asset data and possible risk of maintenance inefficiencies.	Asset Data as per SAP requirements.

4.4.5.1 Future improvements

With the incremental implementation of IEC 61850, JEN is evaluating an advanced multiplexer platform. ABB have created the FOX615 multiplexer platform that is designed for power utilities and act as digital s/s enabler with IEC61850 integrated in the system (TEGO1 card).

Figure 36 – Advanced multiplexer platform ABB FOX615



Potential benefits of moving to a new platform are:

- Multiservice networks for grid operations reduces OPEX:
    - Only one network infrastructure to operate/ maintain;
    - Easier spare part handling and less spares required;
    - Easier life cycle supervision;
    - Easier maintenance and know-how management; and
    - Increased flexibility.
- Multiservice networks increase availability by:
    - Less equipment involved;
    - Utility grade equipment applied; and
    - Faster fault finding and reconfiguration due to better visibility.

4.5 INET RADIO & CELLULAR

4.5.1 INTRODUCTION

The radio transceiver and cellular modem services consists of wireless distribution automation systems (GE MDS iNet radio network and Telstra 3G service) used for communications to:

- Automatic Circuit Reclosers (ACR) pole top radio;
- Remote Control Gas Switches (RCGS) pole top radio;
- Fault Indicators (FI) pole top radio;
- Power Quality Meters (PQM) cellular modems at end of feeder kiosk; and
- Ring Main Units (RMU) cellular modems in a kiosk.

Radio communications systems are designed with access points (AP) that group remote radio sites. JEN's radio communications system has 194 remote radio sites deployed across 15 APs. Each remote site serves an ACR, a RCGS or a FI.

In addition to the 194 MDS iNet radio transceivers, there are 69 Cybertec 3G modems in operation.

4.5.2 RISK

4.5.2.1 Criticality

Asset criticality assessment was conducted by following the Asset Criticality Assessment Procedure (JEM AM PR 0016). Results of this assessment are presented in Appendix A.

This radio transceivers and cellular modems sub-asset class has an asset criticality score of AC3 and the criticality rating of Significant due to the fact that JEN iNet radio and 3G service are deployed to supply SCADA communications to distribution automation devices such as RCGS, ACR, FI, PQM and RMU. If a communications failure occurs during an electricity network fault, restoration of supply could be delayed due to the loss of visibility to the status of the ACR, RCGS or FI.

4.5.2.2 Failure Modes

Types of failure are characterised by the outage of a iNet radio device or 3G device caused by power supply, processor module, antenna and or components failure.

4.5.2.3 Current Risks

Radio transceivers and cellular modems failure risks, types and consequences are captured in Risk Register – Secondary Plant in Jemena Compliance and Risk System (JCARS).

The risk of radio transceivers and cellular modems failure is considered to be 'Significant' based on current Jemena Risk Assessment standard. The major risk associated with this sub-asset class failure has been identified as losing visibility and remote control.

4.5.2.4 Existing Controls

Existing controls for radio transceivers and cellular modems are essentially those maintenance tasks registered on SAP, together with performance monitoring. The radio transceivers and cellular modems are monitored with a dedicated Simple Network Management Protocol (SNMP) server. Technical support staff in duty will be informed immediately after device performance issues and/or faults occur.

Contingency plans are immediate response to system alarms by field crews to resolve the issues. If required, the failed equipment will be replaced with spares from stock.

4.5.2.5 Future Risks

Emerging risks for this sub-asset class are:

- Weak cybersecurity features of the iNet radio v1 system; and
- 3G cellular services being retired by telecommunication carriers.

4.5.3 PERFORMANCE

4.5.3.1 Requirements

The radio transceivers and cellular modems are expected to operate continuously providing its communications capacity up to its rated values to meet the needs of communications to JEN pole top devices with acceptable risks relating to safety, environmental, operational impact and financial costs.

Radio transceivers and cellular modems are selected and installed in accordance with JEN's Communications Design & Installation Standard (JEN PR 0029).

4.5.3.2 Life expectancy

Radio transceivers and cellular modems are expected to be 20 years each based on the manufacturer's estimation and industry experience.

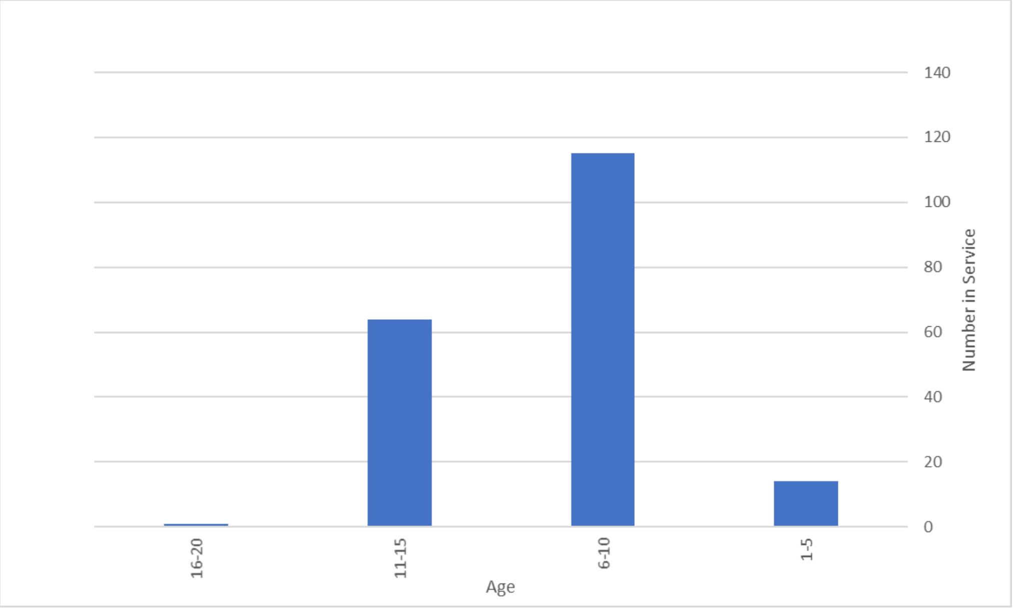
A number of factors determine if an individual radio transceiver or cellular modem has a good probability that it will continue to reliably perform These are CBRM factors of age, condition, utilisation, effectiveness of risk controls and analysis of actual performance are examined.

4.5.3.3 Age profiles

The total number of iNet radio transceivers currently in-service in JEN is 194 and their installation dates are:

- 8 were installed between 2001 and 2005;
- 80 were installed between 2006 and 2010;
- 105 were installed between 2011 and 2015; and
- 1 was installed between 2016 and 2018.

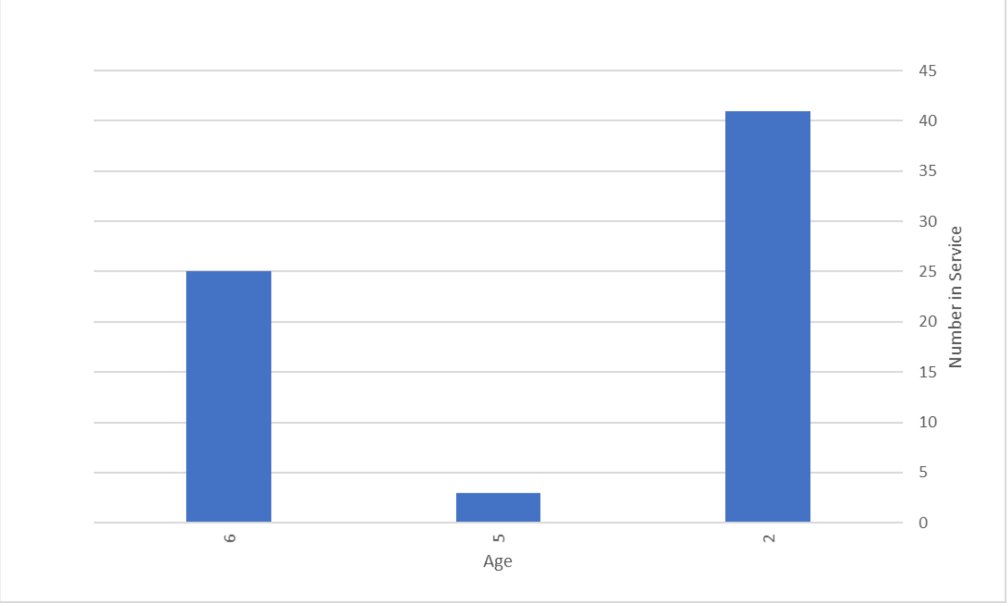
Figure 37 - Age profile of the iNet radio transceivers



The total number of 3G modems currently in-service in JEN is 69 and their installation dates are:

- 28 were installed between 2011 and 2015; and
- 41 were installed between 2016 and 2018.

Figure 38 – Age profile of the cellular modems



4.5.3.4 *Utilisation*

The radio transceivers and cellular modems devices are in-service continuously to monitor and facilitate control.

4.5.3.5 Performance analysis

No significant adverse condition issues have been identified for iNet radio and 3G service in JEN. Replacement technologies for iNet radio is under investigation. 4G service will be deployed to replace 3G from now on.

Root cause analysis is performed for each failure or mal-operation of iNet radio transceivers, 3G modems, radio links or 3G service link.

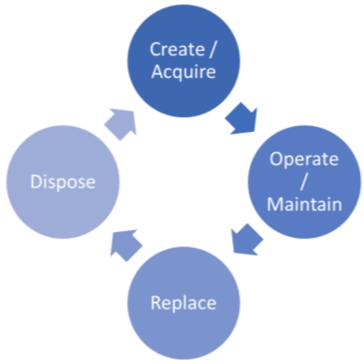
Based on the fault register in SAP and data supplied by Services and Projects SCADA & Communications team, the average number of iNet radio transceivers and 3G modems faults was 6 and 1 respectively each year for the last 7 years; a combined failure rate of < 2%.

4.5.3.6 Controls effectiveness

The principle risk control is real time monitoring of the Network Management System by JEN contractors. This is proven to be highly effective.

4.5.4 LIFE CYCLE MANAGEMENT

4.5.4.1 Creation



Establishment of new radio transceivers and cellular modems comply with A Guideline for Jemena field workers & contractors working in the vicinity of radio frequency fields (JEN GU 0103) and JEN's Communications Design & Installation Standard (JEN PR 0029).

Three scenarios trigger the need to acquire iNet radio and cellular devices:

- Replacement (scheduled upgrade, e.g. replace 3G with 4G);
- New installations; and
- Repair existing installation.

Supplier lead time are 6-8 weeks. Cybertec have discontinued manufacture of 3G modems and now supply 4G modems.

Figure 39 - Quantities of radio transceiver and cellular modem spares

Device type	Quantity	
	Minimum	Maximum
iNet radio transceivers	3	6 (3%)
Cybertec 4G modems	2	4 (5%)

The maximum number of spares is a percentage (%) of the total in-service population of each category of device and is determined by the expected failure rate and lead times.

4.5.4.2 Operation and maintenance

This sub-asset maintenance program involves:

- Preventive maintenance; and
- Reactive maintenance.

Preventative maintenance consists of monitoring, inspection and testing:

- Radio transceiver and cellular modem services are monitored by Services and Projects Field SCADA & Communications team via the SNMP server on a daily basis;
- SAP is updated to reflect all observations and issues observed during the inspections, using asset inspection procedures and documentation;
- The results of the inspection and observations are to be reported to the Asset Manager in the monthly Asset Maintenance Performance report;
- Any potential issues requiring remediation works shall be initiated and managed through the Service Order process in SAP by the Services and Projects Field SCADA & Communications team; and
- It is the responsibility of the Services and Projects Field SCADA & Communications team to ensure that the maintenance records in SAP are accurate at all times.

Reactive maintenance consists of:

- Repair within 24 hours; or
- Replacement (with a spare) within 24 hours.

4.5.4.3 Replacement/disposal

Generally there are three maintenance modes available for this sub-asset life cycle management. The alternative sub-asset replacement modes are:

- Run to failure (reactive);
- Schedule-based replacement (age-based); and
- Condition-based replacement (the most cost effective).

Run to failure means replacement occurs reactively upon failure (irrespective of age or condition).

Schedule-based replacement, in this context, proposes that each radio transceiver or cellular modem is replaced at the end of its respective design/product life. It can also mean replacement driven by a substation refurbishment projects, e.g. protection relay upgrade.

Condition-based replacement is determined by CBRM data:

- Age of asset;
- Preventative maintenance activities and record keeping;
- Performance of asset; and
- Network Management System monitoring.

Decommissioned equipment is disposed of by a certified recycling company in accordance with Jemena Environment Policy (JEM PO 0397).

4.5.5 Information

JEN's AMS (Section 1.2 above) provides a hierarchical approach to understanding the information requirement to achieve Jemena's business objectives at the Asset Class. In summary, the combination of Jemena's Business Plan, the individual Asset Business Strategy (ABS) and Asset Class Strategy (ACS) all provide the context to determine the information required to deliver the sub-asset class' business outcomes.

The high-level information requirements to achieve the ACS's business objectives and inform its critical decisions were identified at a facilitated workshop during the ACS definition process. The radio transceiver and cellular modem sub-asset class identified two business objectives together with the business information required to support these objectives set out in Figure 40. Current and future information requirements to inform value-add decision making are at Figure 41. A proposed improvement future business information need is at Figure 42.

Figure 40 - Radio transceiver and cellular modem services business objectives and information requirements

Business objective	JEN information sources	Externally sourced data
Maintain safety, availability and reliability of radio transceiver and cellular services	▪ ▪ SAP ▪ DrawBridge ▪ SCADA servers ▪ ECMS.	▪ SAI Global; ▪ Manufacture – product information;

		▪ Industry fault history – Distribution Business.

Figure 41 - Radio transceiver and cellular modem services critical decisions business information requirements

Critical business decision	Current information usage	Future information requirement	Value to sub-asset class (High, Medium, Low with justification)
Radio transceiver and cellular services asset creation	• Specifications and tender responses stored on shared network folder. • Zone substation Secondary Design Standard. • JEN IEC61850 Network Design Guide. • JEN Communications Design & Installation Standard. • New asset project progress reporting. Completion recorded in SAP. • Asset register in SAP.		High: Critical component for providing communication links to pole top devices and End of Feeder Power Quality Meters (regulatory).

Maintain functionality of the radio transceiver and cellular services via inspections, and audits	Asset register SAP, with details of each asset and significant components;
	• Manufacturer
	• Type
	• Equipment description
	• Construction year
	• Basic specification
	  ○ Interface type
	  ○ System capability
	• Location of zone substation
	
	Condition Monitoring
	Maintenance reports
	Test reports
	
	Performance history:
	• Plant defect and fault reports
	
	DrawBridge – design drawings/layouts.
	
	SAP notifications and work orders activities performed and components replaced.
	
	Details of work completed recorded in SAP.
		Migrate Condition & Performance reports/data into SAP to improve analysis and decision making.	High: Critical component for providing communication links to pole top devices and End of Feeder Power Quality Meters (regulatory).

Maintain functionality of radio transceiver and cellular services via	• Preventive maintenance tasks, schedules, progress and measurements as applicable in SAP. • Scheduled task description, timing and completion recorded in SAP.	Details of work completed recorded in SAP. All maintenance reports to be attached	High: Critical component for providing communication links to pole top

Critical business decision	Current information usage	Future information requirement	Value to sub-asset class (High, Medium, Low with justification)
preventative maintenance	• Manufacturers maintenance manuals. • SAP notifications and work orders activities performed and components replaced.	to the relevant SAP equipment. Update asset data in SAP for missing data. Details of spare equipment located in SAP.	devices and End of Feeder Power Quality Meters (regulatory).

Maintain functionality of radio transceiver and cellular services via condition monitoring	iNet Radio & 3G Services Functional Location
	• Installation date
	• Model
	• Technology
	• Defect register
	  ○ Events
	  ○ Model
	  ○ Date time
	  ○ Notification number
	Asset operational condition reporting.
		Migrate Condition & Performance reports/data into SAP to improve analysis and decision making.	High: Critical component for providing communication links to pole top devices and End of Feeder Power Quality Meters (regulatory).

Respond to radio transceiver and cellular services defects / faults to restore equipment operationally. Perform corrective maintenance.	• Alerted via network management system. • • Completed corrective maintenance work recorded briefly in SAP. • • Performance history: ○ Plant fault or defect reports. •	Asset failure details and investigation reports are available. Update asset data, including spares, in SAP for missing data.	High: Critical component for providing communication links to pole top devices and End of Feeder Power Quality Meters (regulatory).

Figure 42 - Information initiatives to support business information requirements

Information initiative	Use case description	Asset class risk in not completing	Data quality requirement
Migrate Condition & Performance reports/data into SAP. Update asset data in SAP for missing data.	To improve analysis and decision making. Asset data available from business systems saving on site trips.	Poor efficiency in accessing asset data and possible risk of maintenance inefficiencies.	Asset Data as per SAP requirements.

4.5.5.1 Future improvements

The costs and benefits of moving from iNet radio v1 to v2 are being evaluated. 4G, no longer 3G, Cybertec modems are procured from now on with 5G, potentially, just around the corner.

Generally radio transceiver and cellular modem devices are replaced at the end of design/product life. Typically they are replaced as a standalone project. An exception to this is coming up in 2021 because of the End of feeder PQM project. Twenty-two PQMs shall be upgraded. Simultaneously twenty-two 4G or 5G cellular modems shall be changed out as part of the project.

4.6 REMOTE TERMINAL UNITS

4.6.1 INTRODUCTION

A zone substation Remote Terminal Unit (RTU) plays a critical role in SCADA. Devices such as IEDs connect to the RTU and are controlled via a range of protocols including analogue or discrete digital connections, and TCP/IP based protocols such as DNP3.0 or IEC61850 depending on the type of the substation.

RTUs are critical for the monitoring of JEN secondary systems in the field and zone substations. Performance of the RTU is measured through combined efforts of the JEN SCADA system, JEN Control Room and JEN field support teams.

4.6.2 RISK

4.6.2.1 Criticality

Asset criticality assessments were conducted in line with the Jemena Asset Criticality Assessment Procedure (JEM AM PR 0016). Results of this assessment are presented in Appendix A.

The zone substation RTU sub-asset class has been assessed as AC2 - Moderate Criticality due to the fact that the JEN RTUs facilitate communications between zone substation field SCADA devices, protection & control IEDs and the JEN Control Room.

4.6.2.2 Failure Modes

RTU failures are likely to cause the JEN Control Room to lose visibility and control to these devices depending on the nature of the fault. In the event of faults, loss of connectivity to these devices could result in loss of remote monitoring capabilities and control functionality such as switching.

The failure risks, types and consequences of zone substation RTUs are assessed based on historic RTU platform failure. These issues are generally caused by power supply, processor module, communications module and input/output module failure. CPU performance, memory utilisation and other statistics are logged with worsening trends flagged for intervention.

4.6.2.3 Current Risks

JEN zone substation RTU failure risks, types and consequences are captured in Risk Register – Secondary Plant in Jemena Compliance and Risk System (JCARS).

4.6.2.4 Existing Controls

Existing controls for RTUs are essentially those maintenance tasks registered on SAP, together with performance monitoring.

Contingency plans are immediate response to system alarms by field crews to resolve the issues. If required, the failed equipment will be replaced with spares from stock.

4.6.2.5 Future Risks

An emergent risk is legacy RTUs. Schneider no longer manufacture or support the C50, C60 and SCD5200 models. This risk is mitigated by the current model SDC 6000 which is backwards compatible with the legacy models.

4.6.3 PERFORMANCE

4.6.3.1 Requirements

The performance objective of an RTU asset class is to, in a cost effective manner, maintain reliability of supply to customers and facilitate the safe and efficient functioning of the JEN power system. Impact upon supply reliability can result from failure of an RTU (to communicate with the JEN field SCADA devices, protection relays and head end equipment).

JEN zone substation RTUs are expected to operate continuously providing substation gateway functionality and communications capacity up to their rated specifications.

RTUs are selected and installed in accordance with JEN's Communications Design & Installation Standard (JEN PR 0029).

4.6.3.2 Life Expectancy

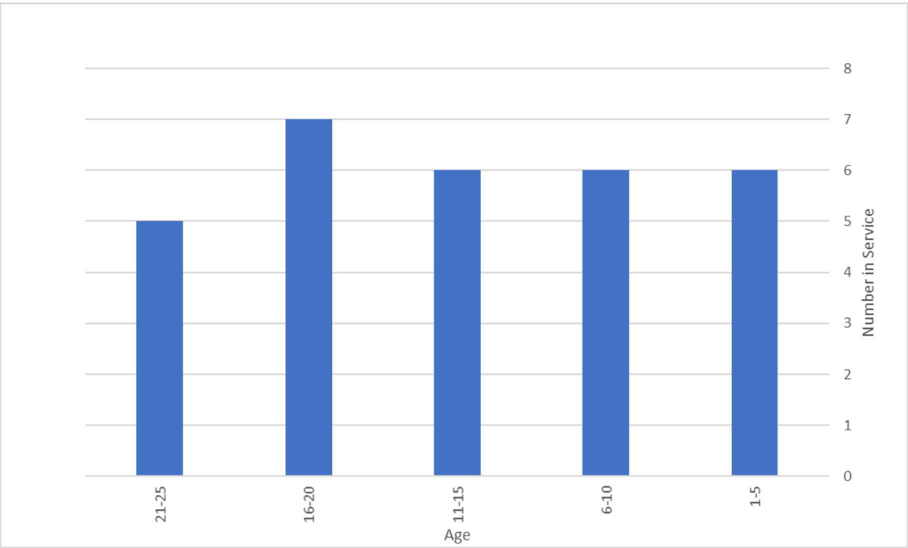
Remote Terminal Units are expected to be 20 years each based on the manufacturer's estimation and industry experience.

A number of factors determine if an individual RTU has a good probability that it will continue to reliably perform These are CBRM factors of age, condition, utilisation, effectiveness of risk controls and analysis of actual performance are examined.

4.6.3.3 Age profiles

There are 30 RTUs.

Figure 43 - Age profile of the RTUs



4.6.3.4 Utilisation

The RTUs are in-service continuously to enable monitoring and control.

4.6.3.5 Performance analysis

Zone substation RTU reliability performance continues to be good despite a number of RTUs approaching the average expected operating life of 20 years of age, IEC61850 standard designed substations utilise station gateways instead of RTUs depending on the approach taken. The distribution of assets and type over coming years might change owing to this.

Root cause analysis is performed for each failure or mal-operation of an RTU.

The performance of the RTU devices is measured via SCADA. Reliability has been good, zone substation RTU defects captured in SAP since 2012 show that in total there have been 8 hardware faults – 3 power supply unit failures, 3 communications module failure, 1 CPU module failure and 1 input/output module failure. RTU software faults are normally fixed by remote system rebooting and are not recorded in SAP.

4.6.3.6 Controls effectiveness

The principle risk control is oversight by SCADA at the JEN Control Room. This is proven to be highly effective.

4.6.4 LIFE CYCLE MANAGEMENT

4.6.4.1 Creation

Two scenarios trigger the need to acquire and install a new RTU:

- To replace an RTU that is beyond economic repair; and
- The building, or refurbishment, of a substation.

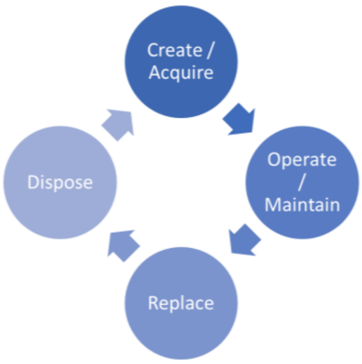


Figure 44 – RTU spares quantities

RTU	Quantity	
	Minimum	Maximum
Schneider SCD6000	2	4
ABB	1	2

Supplier lead times are 6-8 weeks. Schneider no longer manufactures or supports their C50, C60 and SCD5200 models. The SDC 6000 is the current model and is backwards compatible with the legacy models.

4.6.4.2 Operation and maintenance

This sub-asset maintenance program involves:

- Preventive maintenance; and
- Reactive maintenance.

Preventative maintenance consists of continuous monitoring and two yearly inspection and testing:

- RTU operational status and fault statistics are monitored and logged in consultation with the JEN SCADA system by the field SCADA team, and performance trends analysed monthly;
- If SCADA hosts begin to receive error status flags from a zone substation RTU, the RTU will be monitored more closely;
- The operational status of the population of RTUs along with the other communications assets are presented in the monthly asset operation report;
- A scheduled maintenance plan of JEN zone substation RTUs on SAP; and
- RTU maintenance records are also kept in hardcopy.

Reactive maintenance consists of:

- Repair within 24 hours; or
- Replacement (with a spare) within 24 hours.

4.6.4.3 Replacement/disposal

Generally there are three maintenance modes available for this sub-asset life cycle management. The alternative sub-asset replacement modes are:

- Run to failure (reactive);
- Schedule-based replacement (age-based); and
- Condition-based replacement (the most cost effective).

Run to failure means replacement occurs reactively upon failure (irrespective of age or condition).

Schedule-based replacement, in this context, proposes that each RTU is replaced at the end of its respective design/product life. It can also mean replacement driven by a substation refurbishment projects, e.g. protection relay upgrade.

Condition-based replacement is determined by CBRM data:

- Age of asset;
- Preventative maintenance activities and record keeping;
- Performance of asset; and
- Network Management System monitoring.

Decommissioned equipment is disposed of by a certified recycling company in accordance with Jemena Environment Policy (JEM PO 0397).

Figure 45 – RTUs forecast capital expenditure

Location	Year	Reasons for replacement	Comments
FE	2020	• Replacement is necessary to ensure visibility of the ZSS network is available and avoid faults associated with depreciated asset.	• Total CAPEX is $48k.
BY	2021	• The C50 RTU has been in-service for over 20 years and it is out of vendor support • A Cooper station gateway SG4260 with the built in HMI functions will be installed to replace the C50 RTU, HMI functionality is	• Carried out as part of the mitigate risks associated with deteriorated relays - BY project. • Total CAPEX is $48k.

Location	Year	Reasons for replacement	Comments
		required to be retained hence the installation of this nonstandard unit	
CN	2022	• An SG4260 and IO IED will be installed at CN to implement IEC61850 standard.	• Carried out as part of the Replace Aged Relay at CN project. • Total CAPEX is $48k.
CS	2023	• A SG4260 and a IO IED will be installed at CN to implement IEC61850 standard.	• Carried out as part of the mitigate risks associated with deteriorated relays - CS project. • Total CAPEX is $48k.
NH / NEI	2024	• The SCD5200 RTU at NH has been in-service for over 20 years and it is out of vendor support. • An SCD6000 RTU will be installed to replace the SCD5200 based on the current JEN standard.	• Carried out as part of the mitigate risks associated with deteriorated relays – NH / NEI project. • Total CAPEX is $48k.

4.6.5 Information

JEN's AMS (Section 1.2 above) provides a hierarchical approach to understanding the information requirement to achieve Jemena's business objectives at the Asset Class. In summary, the combination of Jemena's Business Plan, the individual Asset Business Strategy (ABS) and Asset Class Strategy (ACS) all provide the context to determine the information required to deliver the sub-asset class' business outcomes.

The high-level information requirements to achieve the ACS's business objectives and inform its critical decisions were identified at a facilitated workshop during the ACS definition process. The RTU sub-asset class identified two business objectives together with the business information required to support these objectives set out in Figure 46. Current and future information requirements to inform value-add decision making are at Figure 47. A proposed improvement future business information need is at Figure 48.

Figure 46 - Zone substation RTU business objectives and information requirements

Business objective	JEN information sources	Externally sourced data
Maintain safety, availability and reliability of zone substation RTUs	▪ SAP ▪ DrawBridge ▪ SCADA servers ▪ ECMS	▪ SAI Global; ▪ Manufacture – product information; ▪ Industry fault history – Distribution Business.

Figure 47 - Zone substation RTU critical decisions business information requirements

Critical Business Decision	Current Information Usage	Future Information Requirement	Value to Asset Class (High, Medium, Low with justification)
Zone substation RTU – Asset Creation	• Specifications and tender responses. • Zone substation Secondary Design Standard. • JEN IEC61850 Network Design Guide. • JEN Communications Design & Installation Standard. • New asset records in SAP at completion of projects .	• Asset information data registration in SAP with full details.	Medium: Functional gateway of both JEN conventional and IEC61850 zone substations.

Maintain functionality of zone substation RTU via inspections, and audits	Asset registration in SAP with the following information:
	• Manufacturer
	• Equipment Type
	• Construction Date
	• Basic Specification
	  ○ Interface type
	  ○ System capability
	• Location of Deployment
	
	DrawBridge – design drawings/layouts.
	
	SAP notifications and work orders activities performed and components replaced.
	
	Details of work completed recorded in SAP.
		• Record inspections and audits reports in SAP.	Medium: Functional gateway of both JEN conventional and IEC61850 zone substations.

Maintain functionality of zone substation RTU via Preventative Maintenance	Preventive maintenance tasks, schedules, progress and measurements as applicable in SAP. Performance history: • Plant defect and fault reports. Scheduled task description, timing and completion recorded in SAP. Manufacturers maintenance manuals. SAP notifications and work orders activities performed and components replaced.	• Record details of completed work in SAP • Attach maintenance reports to the relevant SAP equipment. • Update asset data in SAP for missing data.	Medium: Functional gateway of both JEN conventional and IEC61850 zone substations.
Maintain functionality of zone substation RTU via Condition Monitoring	Zone substation RTU • Functional location • Installation date • Model • Technology • Defect register	• Migrate Condition & Performance reports/data into SAP to improve analysis and decision making.	Medium: Functional gateway of both JEN conventional and IEC61850 zone substations.

Critical Business Decision	Current Information Usage	Future Information Requirement	Value to Asset Class (High, Medium, Low with justification)
	○ Events ○ Model ○ Date time ○ Notification number Asset operational condition reporting.		
Respond to zone substation RTU defects / faults to restore equipment operationally. Perform corrective maintenance.	Alerted via network management system. Completed corrective maintenance work recorded briefly in SAP. Performance history: • Plant fault or defect reports.	• Asset failure details and investigation reports are available. • Update asset data, including spares, in SAP for missing data.	Medium: Functional gateway of both JEN conventional and IEC61850 zone substations.

Figure 48 - Information initiatives to support business information requirements

Information initiative	Use case description	Asset class risk in not completing	Data quality requirement
Migrate Condition & Performance reports/data into SAP. Update asset data in SAP for missing data.	To improve analysis and decision making. Asset data available from business systems saving on site trips.	• Poor efficiency in accessing asset data and possible risk of maintenance inefficiencies.	Asset Data as per SAP requirements.

4.6.5.1 Future improvements

With the incremental implementation of IEC 61850 (partial station bus at BMS and TMA; full station bus at PTN), RTUs other than Schneider models come into play. BMS and TMA have RTUs by ABB. PTN shall have an RTU by Cooper. It may be beneficial to eventually standardise on one make and model (so as to achieve training and inventory efficiencies).

4.7 COMMUNICATIONS NETWORK DEVICES

4.7.1 INTRODUCTION

Communications network devices are expected to operate continuously providing communications capacity within device specifications and adequately to meet communications requirements of protection and control, remote engineering access and SCADA services with acceptable performance, reliability, safety and environmental impact.

Consequences of communications network devices outage could mean:

- Loss of monitoring and system parameter data;
- Loss of visibility of device status;
- Inability to control network elements;
- Longer service restoration due to lack of system monitoring to assist with locating of issues; and
- Longer service restoration time owing to manual switching operations.

JEN has deployed:

- 50 industrial Ethernet switches;
- 3 engineering Human Machine Interfaces (HMI) at IEC 61850 sites (one each at BMS, TMA & PTN); and
- 4 data centre routers (2 at BRO and 2 at ES).

Ethernet Switches: These devices are located within each zone substation, at the network head end and in some cases in ACR cabinets. These devices forward and filter OSI layer 2 traffic between ports. Layer 2 traffic management utilised Media Access Control (MAC) addresses in packets. These devices have multiple ports allowing for star or ring network topology. Additional Ethernet switches can be interlinked or cascaded.

Routers: These are layer 3 devices capable of forwarding traffic between networks by processing routing information included in the packet or datagram. These are located at the head end.

Engineering HMIs: These interfaces are used for engineering access at JEN's IEC 61850 sites (one each at BMS, TMA and PTN).

4.7.2 RISK

4.7.2.1 Criticality

The JEN Asset Criticality Assessment Procedure (JEM AM PR 0016) was adhered to and results of this assessment are presented in Appendix A.

The communications network devices sub asset class has been assessed as AC2 - Moderate Criticality due to the fact that the communications network devices are deployed to supply communications services to field and zone substation SCADA devices for engineering access and monitoring and control.

4.7.2.2 Failure Modes

On the rare occasion there is a failure, it is either:

- A power supply module which does not operate; or
- An install and configuration glitch which does not operate as intended.

4.7.2.3 Current Risks

JEN network device failure risks, types and consequences are captured in Risk Register – Secondary Plant in Jemena Compliance and Risk System (JCARS).

The major risk associated with communications network device failure is loss of visibility and control to secondary systems. During a network fault, this could cause the delay of service restoration. In the great majority of cases physical issues with JEN primary equipment will result in operation of protection. Issues requiring rapid operator intervention are conceivable such as a high impedance fault that is not cleared by protection, one example could be downed wires on dry asphalt or the failure of protection to clear a fault.

4.7.2.4 Existing Controls

Existing controls are put into practice via preventative maintenance (described in the Operation and Maintenance sub-section below) and are effective.

4.7.2.5 Future Risks

Network bandwidth utilisation is within capacity of communication links provided by the equipment and network latencies are adequate. Bandwidth utilisation is not expected to dramatically increase in the foreseeable future however with the implementation of smart grids and interaction with more third parties this could change depending on the evolution of technology.

4.7.3 PERFORMANCE

4.7.3.1 Requirements

A dedicated NMS retrieves network device operational status via the Management Information Base (MIB). Realtime operational status of network devices is monitored, recorded and can be retrieved dynamically.

The mission critical nature of the JEN communications network necessitates redundancy within practical reason. Communications between zone substations are configured in loops and are fully redundant as per this requirement. Switches and IED and RTU connections within zone substations are not fully redundant. The availability and reliability of communications network devices servicing zone substations equipment is expected to be at the same level as that of head end equipment.

Communications network devices are selected and installed in accordance with JEN's Communications Design & Installation Standard (JEN PR 0029).

4.7.3.2 Life Expectancy

Communications network devices are expected to be 20 years each based on the manufacturer's estimation and industry experience.

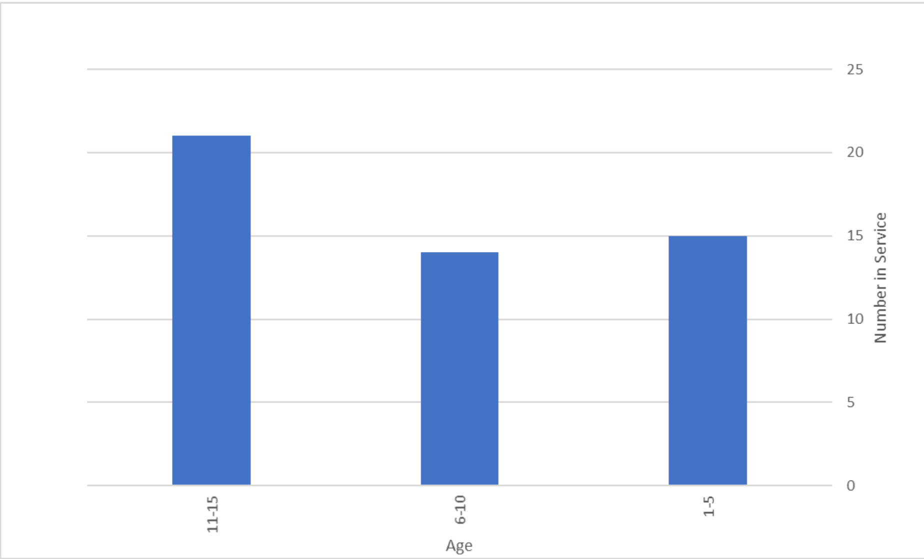
A number of factors determine if an individual radio transceiver or cellular modem has a good probability that it will continue to reliably perform These are CBRM factors of age, condition, utilisation, effectiveness of risk controls and analysis of actual performance are examined.

4.7.3.3 Age profiles

Figure 49 - Age profile for JEN deployed communications network devices

Model	Quantity	Installed between	
Ruggedcom switch	29	2006	2010
Ruggedcom switch	9	2011	2015
Other comms devices	10	2011	2015
Ruggedcom switch	2	2016	present

Figure 50 - Age profile of industrial switches



4.7.3.4 Utilisation

Communications network devices are in-service continuously to enable monitoring and control.

4.7.3.5 Control effectiveness

Given that failure rates have remained constant for the last 7 years, and reliability continues to be excellent, the current controls are deemed effective.

4.7.3.6 Performance analysis

Performance for these devices is classified in terms of reliability, bandwidth, latency and network capacity. Device performance is continuously logged by automated processes and compared with historical performance and performance of similar devices. Devices with worsening trends in performance are more closely monitored and considered for replacement. No issues have been identified with the Ruggedcom industrial Ethernet switches or the other communications network devices, these devices continue to perform well with no worsening trends in performance or reliability apparent.

Historical defect data captured on SAP shows approximately one fault occurred per year since 2012. Root cause analysis is performed for each failure.

4.7.4 LIFE CYCLE MANAGEMENT

4.7.4.1 Creation

Establishment of new communications network devices is in accordance with the JEN Communications Design & Installation Standard (JEN PR 0029).

Three scenarios trigger the need to acquire and install new Communications network devices:

- To replace a communications network device that is beyond economic repair;
- A new communications node; and
- The building, or refurbishment, of a substation

Supplier lead times are 6-8 weeks. Like for like replacement is preferred.

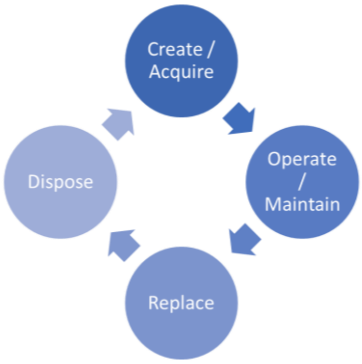


Figure 51 - Spares quantities of communications network devices

Communications network device	Quantities	
	Minimum	Maximum
Ruggedcom switch	2	3
Ruggedcom router	1	1
Engineering HMI	0	0

4.7.4.2 Operation and maintenance

This sub-asset maintenance program involves:

- Preventive maintenance; and
- Reactive maintenance.

Preventative maintenance consists of continuous monitoring and two yearly inspection and testing:

- Communications network devices operational status and fault statistics are continuously monitored by the Communications Infrastructure Team;
- The operational status of the communications network devices, along with the other communications assets, are presented in the monthly asset operations report;
- A scheduled maintenance plan of JEN zone substation communications network devices on SAP' and
- Results of the inspection and observations shall be reported to the Asset Manager in the monthly Asset Maintenance Performance report

Reactive maintenance consists of:

- Repair within 24 hours; or
- Replacement (with a spare) within 24 hours.

4.7.4.3 Replacement/disposal

Working status and parameters of the deteriorated communications network devices are monitored, checked and compared with network device models of similar ages. Results of the comparison are taken into consideration when planning for replacement of communications network devices and may trigger replacement programs.

Generally there are three maintenance modes available for this sub-asset life cycle management. The alternative sub-asset replacement modes are:

- Run to failure (reactive);
- Schedule-based replacement (age-based); and
- Condition-based replacement (the most cost effective).

Run to failure means replacement occurs reactively upon failure (irrespective of age or condition).

Schedule-based replacement, in this context, proposes that each communications network devices is replaced at the end of its respective design/product life. It can also mean replacement driven by a substation refurbishment projects, e.g. protection relay upgrade.

Condition-based replacement is determined by CBRM data:

- Age of asset;
- Preventative maintenance activities and record keeping;
- Performance of asset; and
- Network Management System monitoring.

Decommissioned equipment is disposed of by a certified recycling company in accordance with Jemena Environment Policy (JEM PO 0397).

Figure 52 - Forecast capital expenditure

Location	Year	Reasons for replacement	Coments
FE	2020	• One (1) new Ruggedcom Ethernet switch needs to be installed to meet the IED communications requirement based on the current JEN standard.	• Carried out as part of the FE Switchgear replacement project.
BY	2021	• One (1) new Ruggedcom Ethernet switch needs to be installed to meet the	• Carried out as part of the Mitigate Risks Associated

Location	Year	Reasons for replacement	Coments
		IED communications requirements based on the current JEN standard.	with Deteriorated Relays - BY project.
TBA	2021/2022	• Install 6 MPLS core routers	• Carried out by the JEN PSCN WAN Upgrade project.
CBN	2022	• New Ruggedcom Ethernet switches, routers and other communications equipment required as this is a new JEN zone substation development.	• Carried out as part of the Establish Craigieburn zone substation project.
CN	2022	• New Ruggedcom Ethernet switches, routers and other communications equipment need to be installed to meet the communications requirement of the IEC 61850 zone substation.	• Carried out as part of the Mitigate Risks Associated with Deteriorated Relays - CN project.
CS	2023	• New Ruggedcom Ethernet switches, routers and other communications equipment need to be installed to meet the communications requirement of the IEC 61850 zone substation.	• Carried out as part of the Mitigate Risks Associated with Deteriorated Relays - CS project.
NH/NEI	2024	• One (1) Ruggedcom switch was installed at TTS in 2006 and it needs to be replaced in 2024; • Two (2) new Ruggedcom switches need to be installed at NH to meet the communications requirement based on the current JEN standard.	• Carried out as part of the Mitigate Risks Associated with Deteriorated Relays – NH / NEI project.
BTS & KTS	2025	• Standalone project	• Total CAPEX is $45k.

4.7.5 INFORMATION

JEN's AMS (Section 1.2 above) provides a hierarchical approach to understanding the information requirement to achieve Jemena's business objectives at the Asset Class. In summary, the combination of Jemena's Business Plan, the individual Asset Business Strategy (ABS) and Asset Class Strategy (ACS) all provide the context to determine the information required to deliver the sub-asset class' business outcomes.

The high-level information requirements to achieve the ACS's business objectives and inform its critical decisions were identified at a facilitated workshop during the ACS definition process. The communications network devices sub-asset class identified two business objectives together with the business information required to support these objectives set out in Figure 53. Current and future information requirements to inform value-add decision making are at Figure 54. A proposed improvement future business information need is at Figure 55.

Figure 53 - Communications network devices business objectives and information requirements

Business objective	JEN information sources	Externally sourced data
Maintain safety, availability and reliability of communications network devices	▪ SAP ▪ DrawBridge ▪ SCADA servers ▪ ECMS	▪ SAI Global ▪ Manufacture – product information ▪ Industry fault history – Distribution Business

Figure 54 - Communications network devices critical decisions business information requirements

Critical business decision	Current information usage	Future information requirement	Value to asset class (High, Medium, Low with justification)
Communications network devices - asset creation	• Specifications and tender responses • Zone substation Secondary Design Standard • JEN IEC61850 Network Design Guide • JEN Communications Design & Installation Standard • New asset project progress reporting. Completion recorded in SAP • Asset register in SAP		High: Critical component for Station Bus and Process Bus of the IEC61850 implementation on JEN zone substations.
Maintain functionality of Communications Network Devices via Inspections, and audits	Asset register SAP, with details of each asset and significant components; • Manufacturer • Type • Equipment description • Construction year • Basic specification ○ Interface type ○ System capability • Location: Zone Substation name • Address Condition Monitoring Maintenance reports Test reports Performance history: • Plant defect and fault reports DrawBridge – design drawings/layouts SAP notifications and work orders activities performed and components replaced.	• Migrate Condition & Performance reports/data into SAP to improve analysis and decision making. •	High: Critical to maintain reliability, safety and quality of the operation of secondary system equipment at JEN IEC61850 zone substations.

Critical business decision	Current information usage	Future information requirement	Value to asset class (High, Medium, Low with justification)
	Details of work completed recorded in SAP		
Maintain functionality of Communications Network Devices via Preventative Maintenance	• Preventive maintenance tasks, schedules, progress and measurements as applicable in SAP. • Scheduled task description, timing and completion recorded in SAP. • Manufacturers maintenance manuals • SAP notifications and work orders activities performed and components replaced.	• Details of work completed recorded in SAP. • All maintenance reports to be attached to the relevant SAP equipment. • Update asset data in SAP for missing data. • Details of spare equipment located in SAP	High: Critical to maintain reliability, safety and quality of the operation of secondary system equipment at JEN IEC61850 zone substations.

Maintain functionality of Communications Network Design via Condition Monitoring	Communications Network Devices Functional Location
	• Installation date
	• Model
	• Technology
	• Defect register
	  ○ Events
	  ○ Model
	  ○ Date time
	  ○ Notification number
	Asset operational condition reporting.
		• Migrate Condition & Performance reports/data into SAP to improve analysis and decision making.	High: Critical to maintain reliability, safety and quality of the operation of secondary system equipment at JEN IEC61850 zone substations.

Respond to Communications Network Devices defects / faults to restore equipment operationally. Perform corrective maintenance.	Alerted via network management system. Completed corrective maintenance work recorded briefly in SAP. Performance history: • Plant fault or defect reports.	• Asset failure details and investigation reports are available. • Update asset data, including spares, in SAP for missing data.	High: Critical to maintain reliability, safety and quality of the operation of secondary system equipment at JEN IEC61850 zone substations.

Figure 55: Information Initiatives to Support Business Information Requirements

Information initiative	Use case description	Asset class risk in not completing	Data quality requirement
Migrate condition & performance reports/data into SAP. Update asset data in SAP for missing data.	• To improve analysis and decision making. • Asset data available from business systems saving on site trips. •	• Poor efficiency in accessing asset data and possible risk of maintenance inefficiencies.	Asset Data as per SAP requirements.

4.7.5.1 *Future improvements*

Limited communications network devices related defect history data is available on SAP. A system is planned to be established to capture all necessary information in SAP for efficient performance analysis.

Whilst it is envisaged that replacement of switches shall continue on the same ruggedized platform (using the latest model), where a different standard, such as IEC61850, is introduced the switching platform shall require additional technological capabilities to support GOOSE messaging. It may be beneficial to eventually standardise on one make and model (so as to achieve training and inventory efficiencies).

4.8 GPS CLOCKS

4.8.1 INTRODUCTION

This JEN Global Positioning System (GPS) clocks sub-asset class strategy provides an asset overview, while identifying the best plans for managing these assets over their life cycles. This sub-asset class strategy is based on key information about the asset (including risk, performance, life cycle management and expenditure estimates).

GPS clocks are deployed to synchronise time stamping of Intelligent Electronic Devices (also known as relays) and field SCADA devices.

This sub-asset class strategy aims to maximise the return on investment through:

- Optimisation of augmentation/investment costs through strategic sourcing and effective evaluation of options; and
- Optimisation of maintenance costs through an effective maintenance plan.

The objective of the GPS clocks sub-asset class is to help maintain reliability of supply to customers in the most cost effective manner. The loss of GPS clock data for synchronisation of IED and other zone substation equipment clocks can impact upon the ability to accurately analyse system events because there would be no time stamping recorded.

4.8.2 RISK

4.8.2.1 Criticality

Precise time stamp data resulting in millisecond sequence of events information is crucial to the investigation of JEN distribution faults. It is important to have GPS clocks functioning at all times. Less precise or inaccurate time stamping of sequence of event information due to unsynchronised IED clocks adversely impacts fault investigations.

This sub-asset class has a low criticality, determined by

- Recognition that GPS clocks are essential but their failure does not have immediate effect
- No possibility to impact customer supply

The asset criticality assessment was conducted as per the Jemena Asset Criticality Assessment Procedure (JEM AM PR 0016). Results of this assessment are presented in Appendix A.

4.8.2.2 Failure modes

GPS clock functionality is considered lost if it fails to provide accurate time synchronisation data to field IEDs. This could be caused by a number of factors such as age related deterioration of components or power supply failure. These hardware faults require repair or replacement of the unit.

Loss of satellite signal acquisition will also be considered a failure as unit time synchronisation will rapidly become inaccurate because the unit is unable to receive GPS synchronisation signals. GPS signal acquisition loss could be caused by factors external to the unit including failure of antenna or cabling, physical obstruction of antenna line of site to the sky or other interference.

Risk associated with this type of GPS clock failure is assessed as low impact and low likelihood. Risks associated with an outage of GPS clock receiver are not immediate (clock errors in attached equipment take time to accumulate although they do eventually become significant). These risks are fairly easily managed through rapid repair or replacement as failures occur.

4.8.2.3 Current risks

The failure risks, types and consequences for GPS clock equipment in JEN are captured in the Risk Register – Secondary Plant in Jemena Compliance and Risk System (JCARS).

GPS clocks are generally very reliable and the risk of failure during a network fault is considered to be 'minor'.

4.8.2.4 Existing controls

Operational status of these devices is monitored by the Network Management System.

4.8.2.5 Future risks

No emergent risk has been identified.

4.8.3 PERFORMANCE

4.8.3.1 Requirements

Each GPS clock must support satellite connectivity and provide 24/7 time synchronisation of protection relays so as to allow sequence of events analysis defined to the millisecond.

4.8.3.2 Life Expectancy

The life expectancy for the Abbey and Tekron makes are 7 and 20 years respectively. The Abbey's are old technology and are being phased out. The newer Tekron's are manufactured to align with the product life of an IED, i.e. 20 years.

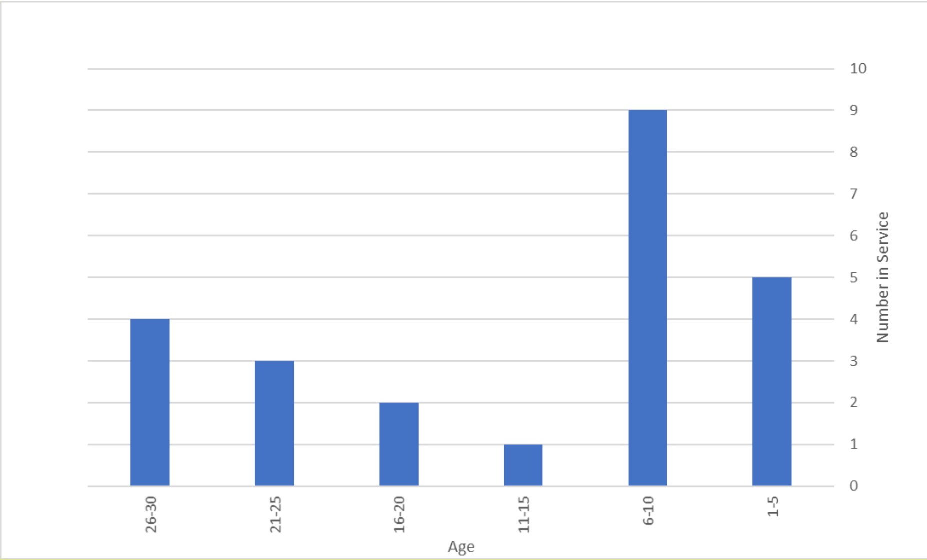
4.8.3.3 Age Profiles

There are 24 GPS Clocks deployed in JEN zone substations. Of the 24 GPS Clocks, 4 are Abbey B06-061 Clocks and 20 are TEKRON GPS Clocks.

Figure 56 – GPS clocks install base by brand

Model	Quantity	Installed between	
Abbey B06-061	4	2001	2005
Abbey B06-061	3	2006	2010
TEKRON GPS TCG 01	2	2011	2015
TEKRON GPS TCG 01 E	1	2006	2010
TEKRON GPS TCG 01 E	9	2011	2015
TEKRON GPS TCG 01 G	5	2016	2017

Figure 57 - Age profiles for GPS clocks



4.8.3.4 Utilisation

A GPS clock is utilised whenever there is a relay event and GPS data is required.

4.8.3.5 Performance Analysis

The actual failure rate is one fault per year (over the last 6 years). These have occurred with each make and have been due to faulty power supplies or resistive joints.

No significant issues have been identified for more recent models such as the Tekron TCG-01 E and Tekron TCG-01 G series devices. Obsolescence has been identified with the Abbey B06-061 and TEKRON TCG 01 models.

The Abbey B06-061 is a legacy model in-service at 4 zone substations (Coburg South, East Preston, Flemington and Footscray West). There is a CAPEX plan to replace this model at Coburg South, Flemington and Footscray West. No replacement plan has been made for East Preston because that zone substation shall be decommissioned in 2023.

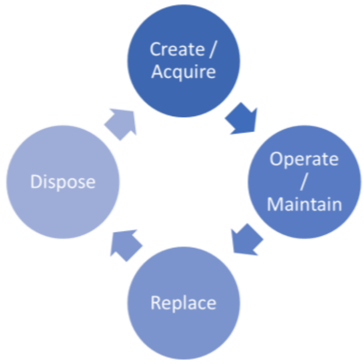
TEKRON TCG 01 GPS clocks installed at Essendon, Footscray East, Newport and Somerton are experiencing similar issues to the Abbey B06-61 and replacements are also planned.

4.8.3.6 Control Effectiveness

The principle risk control is real time monitoring of the Network Management System by JEN contractors. This is proven to be highly effective.

4.8.4 LIFE CYCLE MANAGEMENT

4.8.4.1 Creation



New GPS clock installations are built in accordance with guidelines to working in vicinity of Radio Frequency document (JEN GU 0103) and the JEN Communications Design & Installation Standard (JEN PR 0029).

Three scenarios trigger the need to acquire and establish new GPS clocks:

- New construction such as zone substation, data centre or communications room facilities;
- Upgrade of existing GPS clocks; and
- Reactive replacement.

Figure 58 – Quantity of spares

Model	Quantity	
	Minimum	Maximum
Tekron	1	2

4.8.4.2 Operation and maintenance

Generally there are three maintenance modes available for this sub-asset life cycle management. The alternative sub-asset replacement modes are:

- Run to failure (reactive);
- Schedule-based replacement; and
- Condition-based replacement (the most cost effective).

GPS clocks do not readily fall into any single mode. They have no moving parts and are housed so as to be protected from the elements.

Run to failure means take no action. Run to failure means replacement occurs reactively upon failure (irrespective of age or condition).

Scheduled replacement, in this context, does not mean replacement simply based on age. It means co-ordinating replacement with IED upgrade projects.

Condition monitoring, as already mentioned, is performed over the Network Management System. In addition, each GPS clock is visually inspected annually by the JEN contractor. A check is also made at that time to ensure the IED is displaying the correct time. It is the responsibility of the JEN contractor to ensure that maintenance records in SAP are accurate at all times including information on failures.

The annual inspection ensures units are clean and dust free with no objects intruding into the chassis and all terminals are tight, sockets properly seated and enclosures corrosion free. The unit should be sheltered and not exposed to excessive conditions such as prolonged direct sunlight, humidity, moisture, temperature or vibration. Any heatsink should be clean and free of dust.

Any decommissioned equipment is disposed of by a certified recycling company in accordance with Jemena Environment Policy (JEM PO 0397).

4.8.4.3 Replacement/disposal

Five new/replacement Tekron GPS clocks are scheduled in the coming years.

Figure 59 – GPS clocks capital expenditure

Location	Timeframe	Reason for replacement	Comments
FE	2020	• Abbey B06-061 installed 2005 • Out of vendor support, not working with the current deployed FE zone substation protection relays	To be carried out as part of the FE Switchgear replacement project
BY	2021	• No GPS clock in-service	• Carried out as part of the program - risk mitigation associated with deteriorated relays - BY project
CN	2022	• No GPS clock in-service	• Carried out as part of the program - risk mitigation associated with deteriorated relays - CN project
CBN	2022	• New zone substation to be established	• Carried out as part of the Craigieburn zone substation project
CS	2023	• Abbey B06-061 change out • Out of vendor support, not working with the current deployed CS zone substation protection relays	• Carried out as part of the risk mitigation associated with deteriorated relays - CS project

4.8.5 INFORMATION

JEN's AMS (Section 1.2 above) provides a hierarchical approach to understanding the information requirement to achieve Jemena's business objectives at the Asset Class. In summary, the combination of Jemena's Business Plan, the individual Asset Business Strategy (ABS) and Asset Class Strategy (ACS) all provide the context to determine the information required to deliver the sub-asset class' business outcomes.

The high-level information requirements to achieve the ACS's business objectives and inform its critical decisions were identified at a facilitated workshop during the ACS definition process. The GPS clocks sub-asset class identified two business objectives together with the business information required to support these objectives set out in Figure 60. Current and future information requirements to inform value-add decision making are at Figure 61. A proposed improvement future business information need is at Figure 62.

Figure 60 - GPS clocks business objectives and information requirements

Business objective	JEN information sources	Externally sourced data
Maintain safety, availability and reliability of GPS clocks	▪ SAP ▪ DrawBridge ▪ SCADA servers ▪ ECMS	▪ SAI Global ▪ Manufacture – product information ▪ Industry fault history – Distribution Business

Figure 61 - GPS clocks critical decisions business information requirements

Critical business decision	Current information usage	Future information requirement	Value to Asset Class (High, Medium, Low with justification)
GPS Clocks - Asset Creation	• Specifications and tender responses stored on shared network folder. • Zone substation Secondary Design Standard • JEN IEC61850 Network Design Guide • JEN Communications Design & Installation Standard • New asset project progress reporting. Completion recorded in SAP • Asset register in SAP		High: Critical component for Station Bus and Process Bus time synchronisation of the IEC61850 implementation on JEN zone substations.

Maintain functionality of the GPS Clocks via Inspections, and audits	Asset register SAP, with details of each asset and significant components
	• Manufacturer
	• Type
	• Equipment description
	• Construction year
	• Basic specification
	  ○ Interface type
	  ○ Supported output timing standard
	• Location: Z/substation name
	• Address
	
	Condition Monitoring
	Maintenance reports
	Test reports
	
	Performance history
	• Plant defect and fault reports
	
	DrawBridge – design drawings/layouts
		Migrate Condition & Performance reports/data into SAP to improve analysis and decision making	High: Critical to maintain reliability, safety and quality of the operation of secondary system equipment at JEN IEC61850 zone substations

Critical business decision	Current information usage	Future information requirement	Value to Asset Class (High, Medium, Low with justification)
	SAP notifications and work orders activities performed and components replaced. Details of work completed recorded in SAP		
Maintain functionality of GPS Clocks via Preventative Maintenance	• Preventive maintenance tasks, schedules, progress and measurements as applicable in SAP • Scheduled task description, timing and completion recorded in SAP • Manufacturers maintenance manuals • SAP notifications and work orders activities performed and components replaced	Details of work completed recorded in SAP. All maintenance reports to be attached to the relevant SAP equipment. Update asset data in SAP for missing data. Details of spare equipment located in SAP	High: Critical to maintain reliability, safety and quality of the operation of secondary system equipment at JEN IEC61850 zone substations

Maintain functionality of GPS Clocks via Condition Monitoring	GPS clock Functional Location
	• Installation date
	• Model
	• Technology
	• Defect register
	    ○ Events
	    ○ Model
	    ○ Date time
	    ○ Notification number
	Asset operational condition reporting
		Migrate Condition & Performance reports/data into SAP to improve analysis and decision making	High: Critical to maintain reliability, safety and quality of the operation of secondary system equipment at JEN IEC61850 zone substations

Respond to GPS Clocks defects / faults to restore equipment operationally. Perform corrective maintenance.	Alerted via network management system. Completed corrective maintenance work recorded briefly in SAP Performance history: • Plant fault or defect reports	Asset failure details and investigation reports are available Update asset data, including spares, in SAP for missing data.	High: Critical to maintain reliability, safety and quality of the operation of secondary system equipment at JEN IEC61850 zone substations

Figure 62 - Information initiatives to support business information requirements

Information initiative	Use case description	Asset class risk in not completing	Data quality requirement
• Migrate Condition & Performance reports/data into SAP • Update asset data in SAP to include missing data	• To improve analysis and decision making • Asset data available from business systems saving on site trips	• Poor efficiency in access to asset data and possible risk of maintenance inefficiencies. Loss of important historic reliability data	Asset Data as per SAP requirements

4.8.5.1 Future improvements

Not applicable for this sub-asset.

5 CONSOLIDATED PLAN

This section provides information about:

- Forecast capital expenditure; and
- Forecast operational expenditure

5.1 FORECAST CAPITAL EXPENDITURE

5.1.1 PROTECTION & CONTROL EQUIPMENT

Figure 63 - CAPEX for protection & control to 2026

Project name	$000					
	2021	2022	2023	2024	2025	2026
Replace Aged Relays - BD	$0	$0	$0	$0	$0	$0
Replace BY 22kV Feeder Relays	$772	$775	$0	$0	$0	$0
Replace Relays - CN	$0	$160	$3,370	$2,047	$0	$0
Replace Aged Relays - CS	$0	$0	$0	$1,237	$3,411	$2,809
Relay Replacement - FW	$3,080	$2,249	$0	$0	$0	$0
Replace NH NEI (incl TTS) Relays	$0	$0	$0	$0	$1,164	$1,485
Replace Aged Relays - NS	$0	$0	$0	$0	$0	$2,256
Purchase Secondary Spares	$63	$63	$64	$64	$0	$0
P&C relays secure access management solution	$316	$633	$631	$320	$0	$0
CAPEX totals	**$4,232**	**$3,879**	**$4,065**	**$3,668**	**$4,574**	**$6,549**

5.1.2 DC SUPPLY SYSTEMS

Figure 64 - CAPEX for DC supply systems to 2026

Project name	$000					
	2021	2022	2023	2024	2025	2026
BY & CS Batteries & Chargers Replacement	$0	$0	$0	$0	$0	$0
SHM Batteries Replacement	$0	$125	$0	$0	$0	$0
PV, NT, VCO and Spares Battery & Charger Replacement	$289	$401	$0	$0	$0	$0
ST and TH Battery & Charger Replacement	$0	$0	$471	$0	$0	$0
NEI, VCO and YVE Battery & Charger Replacement	$0	$0	$0	$605	$209	$0

BMS, TMA and EPN Battery & Charger Replacement	$0	$0	$0	$0	$450	$295
CAPEX totals	**$289**	**$526**	**$471**	**$605**	**$659**	**$295**

5.1.3 SUBSTATION & DISTRIBUTION AUTOMATION

5.1.3.1 Communications cabling

The budget forecast for communications cabling includes construction of FOC in 2022 to establish JEN Craigieburn zone substation.

Figure 65 - CAPEX for communication cabling to 2026

Project name	$000					
	2021	2022	2023	2024	2025	2026
Establish Craigieburn (CBN zone substation)	$0	$450	$0	$0	$0	$0
CAPEX totals	**$0**	**$450**	**$0**	**$0**	**$0**	**$0**

5.1.3.2 Multiplexer

The replacement costs associated with Multiplexers is approximately $80k, which are combined with protection upgrade projects as seen below, **with the exception of the *$320K NH/NEI project initiative for 2024**.

Figure 66 – CAPEX for multiplexers to 2026

Project name	$000					
	2021	2022	2023	2024	2025	2026
Mitigate risks associated with deteriorated relays - BY	$0	$80	$0	$0	$0	$0
Mitigate risks associated with deteriorated relays - CN	$0	$0	$0	$0	$80	$0
Mitigate risks associated with deteriorated relays - CS	$0	$0	$80	$0	$0	$0
Mitigate risks associated with deteriorated relays - NH/NEI	$0	$0	$0	***$320**	$0	$0
Replace comms equipment at BTS & KTS (7 Mux & 3 Sw)	$0	$0	$0	$0	$330	$0
Establish Craigieburn (CBN zone substation)	$0	$80	$0	$0	$0	$0
CAPEX totals	**$0**	**$160**	**$80**	**$320**	**$410**	**$0**

5.1.3.3 Radio transceiver & cellular services

The 3G/4G replacement has been combined with End Of Feeder PQM CAPEX replacement, as these are the communications media for the PQMs. The cost component of the 3G replacement is approximately $100k of the total project cost.

The replacement CAPEX project of radio transceivers will be completed as a program of work over various years as shown in the table below.

Figure 67 – CAPEX for iNet radio & cellular services to 2026

Project name	$000					
	2021	2022	2023	2024	2025	2026
Replace iNet radio transceivers	*$48	*$110	*$61	*$25	*$126	*$159
Replace 3G/4G modems	$100	$0	$0	$0	$0	$0
CAPEX totals	**$148**	**$110**	**$61**	**$25**	**$126**	**$159**

5.1.3.4 RTUs

All JEN deployed zone substation RTU replacement is aligned with JEN protection and control equipment projects and the CAPEX amounts are subsumed into those projects.

Figure 68 – CAPEX for zone substation RTUs to 2026

Project name	$000					
	2021	2022	2023	2024	2025	2026
Mitigate risks associated with deteriorated relays - BY	$48	$0	$0	$0	$0	$0
Mitigate risks associated with deteriorated relays - CN	$0	$48	$0	$0	$0	$0
Mitigate risks associated with deteriorated relays - CS	$0	$0	$48	$0	$0	$0
Mitigate risks associated with deteriorated relays - NH/NEI	$0	$0	$0	$0	$48	$0
Replacement FE switchgear	$0	$0	$0	$0	$0	$0
Establish Craigieburn (CBN zone substation)	$0	$48	$0	$0	$0	$0
CAPEX totals	**$48**	**$96**	**$48**	**$0**	**$48**	**$0**

5.1.3.5 Communications network devices

All JEN deployed network devices replacement is aligned with JEN protection and control equipment projects, **with the exception of the *$204K BTS & KTS standalone project slated for 2025 * 2026**.

Figure 69 - CAPEX for communication network devices to 2026

Project name	$000					
	2021	2022	2023	2024	2025	2026
Mitigate risks associated with deteriorated relays - BY	$15	$0	$0	$0	$0	$0
Mitigate risks associated with deteriorated relays - CN	$0	$30	$0	$0	$0	$0
Mitigate risks associated with deteriorated relays - CS	$0	$0	$30	$0	$0	$0
Mitigate risks associated with deteriorated relays - NH/NEI	$0	$0	$0	$0	$45	$0

Replacement FE switchgear	$0	$0	$0	$0	$0	$0
Establish Craigieburn (CBN zone substation)	$0	$45	$0	$0	$0	$0
Replace COMM's Equipment at BTS & KTS(7 MUX, 3 SW)	$0	$0	$0	$0	*$204	*$204
CAPEX totals	**$15**	**$75**	**$30**	**$0**	**$249**	**$204**

5.1.3.6 GPS clocks

The replacement GPS Clocks project has been aligned with the upgrading of primary plant and secondary plant at each zone substation and the CAPEX amounts are subsumed into a larger project.

Figure 70 - CAPEX for GPS clocks to 2026

Project name	$000					
	2021	2022	2023	2024	2025	2026
Mitigate Risks Associated with Deteriorated Relays - BY	$7	$0	$0	$0	$0	$0
Mitigate Risks Associated with Deteriorated Relays - CN	$0	$7	$0	$0	$0	$0
Mitigate Risks Associated with Deteriorated Relays - CS	$0	$0	$7	$0	$0	$0
Replacement FE Switchgear	$0	$0	$0	$0	$0	$0
Establish Craigieburn (CBN zone substation)	$0	$7	$0	$0	$0	$0
CAPEX totals	**$7**	**$14**	**$7**	**$0**	**$0**	**$0**

5.2 OPERATING AND MAINTENANCE FORECAST

5.2.1 PROTECTION & CONTROL EQUIPMENT

The maintenance plan for JEN's protection and control equipment is implemented in SAP. The below amounts are based on the estimates and average yearly cost of the maintenance tasks between 2012 and 2016, collated from SAP data.

Figure 71 – OPEX for protection and control to 2026

Maintenance	$000					
	2021	2022	2023	2024	2025	2026
Expenditure - defect maintenance (reactive)	$65	$66	$68	$71	$72	$74
Expenditure - routine maintenance (preventative)	$95	$97	$100	$103	$106	$108
OPEX totals	**$160**	**$163**	**$168**	**$174**	**$178**	**$182**

5.2.2 DC supply systems

The maintenance plan for JEN's DC supply systems is implemented in SAP. The below amounts are based on the estimates and average yearly cost of the maintenance tasks between 2012 and 2016, collated from SAP data.

Figure 72 – OPEX for DC supply systems to 2026

Maintenance	$000					
	2021	2022	2023	2024	2025	2026
Preventative	$46	$47	$48	$50	$51	$51
Reactive	$28	$29	$30	$30	$31	$31
OPEX totals	**$74**	**$76**	**$78**	**$80**	**$82**	**$82**

5.2.3 SUBSTATION & DISTRIBUTION AUTOMATION

Maintenance planning for all JEN deployed substation and distribution automation equipment has been registered on SAP. The annual cost of each SDA sub-asset class listed (sub-sections 5.2.3-8 below) is calculated based on the registered maintenance plan.

5.2.3.1 Communications cabling

The maintenance plan for Communications Cables covers only the maintenance (visual inspection and twisted pair resistance and insulation tests) of Copper Supervisory Cables. The visual inspection of JEN fibre optic cables has recently been included in JEN Asset Inspection Manual and no extra cost (based on the existing JEN asset inspection specified on the manual) is expected. FOC maintenance cost database will be established when results are available with the implementation of the visual inspection.

The forecast operational expenditure is based on the average history defects data from SAP and JEN field operational staff.

Based on the current JEN *Copper Supervisory Cable Decommission Strategy* (ELE AM PL 0002), budget is planned to get the decommissioned copper supervisory cables in JEN from 2021 to 2025 as listed on table 5.2.6.1 below.

Figure 73 - OPEX for comms cabling to 2026

Maintenance	$000					
	2021	2022	2023	2024	2025	2026
Preventative	$15	$15	$15	$16	$16	$16
Reactive	$100	$103	$105	$108	$111	$113
Removal of decommissioned OH Cu supervisory cable	$600	$200	$200	$300	$200	$100
OPEX totals	**$715**	**$318**	**$320**	**$424**	**$327**	**$229**

5.2.3.2 Multiplexer

The maintenance plan for the multiplexers in-service in JEN has been registered on SAP. The plan covers the routine maintenance of the PDH multiplexers and their components from hardware, firmware, configuration and topology function perspective.

The forecast operational expenditure is based on the average history defects data from SAP and JEN field operational staff.

Figure 74 - OPEX for Mux to 2026

Maintenance	$000					
	2021	**2022**	**2023**	**2024**	**2025**	**2026**
Preventative	$46.9	$48.2	$49.5	$50.7	$52.0	$53.3
Reactive	$12.6	$13.0	$13.3	$13.7	$14.0	$14.3
OPEX totals	**$59.5**	**$61.2**	**$62.8**	**$64.4**	**$66.0**	**$67.6**

5.2.3.3 Radio transceiver & cellular services

The maintenance plan for JEN deployed radio and 3G services has been registered on SAP. The plan covers the inspection of the radio transceivers and 3G modems; radio signal strength, equipment configuration and system event history check.

The forecast operational expenditure is based on the average history defects data from SAP and JEN field operational staff.

Figure 75 - OPEX for iNet radio & cellular to 2026

Maintenance	$000					
	2021	**2022**	**2023**	**2024**	**2025**	**2026**
Preventative	$34.3	$35.2	$36.2	$37.1	$38.0	$39.0
Reactive	$10.8	$11.1	$11.4	$11.7	$12.0	$12.3
OPEX totals	**$45.1**	**$46.4**	**$47.6**	**$48.8**	**$50.0**	**$51.3**

5.2.3.4 RTUs

Maintenance plan for JEN zone substation RTU covers check and inspection of hardware system (including the interface modules), system configuration and signal levels of the input/output channels.

The forecast operational expenditure is based on the average history defects data from SAP and JEN field operational staff.

Figure 76 – OPEX for RTUs to 2026

Maintenance	$000					
	2021	**2022**	**2023**	**2024**	**2025**	**2026**
Preventative	$18.9	$19.4	$19.9	$20.4	$20.9	$21.4
Reactive	$4.4	$4.5	$4.6	$4.7	$4.8	$4.9
OPEX totals	**$23.2**	**$23.8**	**$24.5**	**$25.1**	**$25.7**	**$26.3**

5.2.3.5 Communications network devices

The annual cost of JEN Communications Network Devices maintenance plan, which covers the check of equipment configuration, system resource utilisation and system status, is shown on the table below.

The forecast operational expenditure is based on the average history defects data from SAP and JEN field operational staff.

Figure 77 - OPEX for communications network devices to 2026

Maintenance	2021	2022	2023	2024	2025	2026
Preventative	$30.0	$30.8	$31.6	$32.5	$33.3	$34.1
Reactive	$2.6	$2.6	$2.7	$2.8	$2.9	$2.9
OPEX totals	**$32.6**	**$33.5**	**$34.4**	**$35.2**	**$36.1**	**$37.0**

5.2.3.6 GPS clocks

The maintenance plan for JEN deployed GPS clocks covers inspection of the GPS clocks kit (including antenna, antenna cable and the connection from the GPS clocks to the attached equipment); the configuration and synchronisation status of the GPS Clocks.

The forecast operational expenditure is based on the average history defects data from SAP and JEN field operational staff.

Figure 78 - OPEX for GPS clocks to 2026

Maintenance	$000					
	2021	2022	2023	2024	2025	2026
Preventative	$1.6	$1.6	$1.7	$1.7	$1.7	$1.8
Reactive	$1.1	$1.2	$1.2	$1.2	$1.2	$1.3
OPEX totals	**$2.7**	**$2.8**	**$2.8**	**$2.9**	**$2.9**	**$3.0**

6 GLOSSARY

6.1 ZONE SUBSTATION ABBREVIATIONS

Substation	Suburb
AW	Airport West
BD	Coolaroo
BMS	Broadmeadows
BY	Maidstone
CN	Coburg Nth
COO	Coolaroo
CS	Coburg Nth
EP	Preston
EPN	Preston
ES	Essendon
FE	Yarraville
FF	Fairfield
FT	Flemington
FW	Yarraville
HB	Heidelberg
MAT	Melbourne Airport
NEI	Heidelberg West
NH	Macleod
NS	Essendon
NT	Newport
PTN	Preston
PV	Pascoe Vale
SBY	Sunbury
SHM	Sydenham
SSS	Somerton
ST	Somerton
TH	Tottenham
TMA	Tullamarine
VCO	Coolaroo
YVE	Yarraville

6.2 ACRONYMS

ABS	Asset Business Strategy
AC	Alternating Current
ACR	Automatic Circuit Recloser
ACS	Asset Class Strategy
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
AMI	Advanced Metering Infrastructure
AMS	Asset Management System
BAU	Business As Usual
BI	Business Intelligence
CATS	Customer Administration Transfer System
CBRM	Condition Based Risk Management
COWP	Capital Operating Works Program
CPU	Central Processing Unit
CT	Current Transformer
DAPR	Distribution Annual Planning Report
DC	Direct Current
DNSP	Distribution Network Service Provider
EDPR	Electricity Distribution Price Review
ENA	Energy Networks Association
EOL	End of Life
EPA	Environment Protection Authority
ERP	Enterprise Resource Planning
ESCV	Emergency Services Commission of Victoria
ESMS	Energy Safe Management Scheme
ESV	Energy Safe Victoria
EUSE	Expected Unserved Energy
GPS	Global Positioning System
HSE	Health, Safety and Environment
HV	High Voltage
I/O	Input/Output
IED	Intelligent Electronic Device (typically a digital protection relay)
JCAR	Jemena Compliance & Risk System
JEN	Jemena Electricity Networks (Vic) Ltd
JSAP	Jemena SAP
KPI	Key Performance Indicator
kV	kiloVolt
KVAR	Kilo-Amps-Volts-Reactive
KW	Kilowatt
LCD	Liquid Crystal Display
LV	Low Voltage
MAMS	Metering Asset Management Strategy
MDM	Meter Data Management
MIB	Management Information Base
MTBF	Mean Time Between Failure

MW	Megwatt
NER	National Electricity Regulator
NIC	Network Interface Card
NMS	Network Management Systems
NOC	Netwrok Operations Centre
PQCA	Power Quality Compliance Audit
PQM	Power Quality Meter
PSCN	Power Supply Control Network
RAM	Random Access Memory
RIN	Regulatory Information Notice
ROM	Read Only Memory
RTS	Real Time System
RTU	Remote Terminal Unit
SAP	Proprietory name for ERP sofware
SCADA	Supervisory Control and Data Acquisition
SMR	Switch Mode Rectifier
VEDC	Victorian Electricity Distribution Code
VESC	Victorian Electricity System Code
VT	Voltage Transformer
ZSS	Zone Substation

6.3 TERMS AND DEFINITIONS

Capital expenditure (CAPEX)	Expenditure to buy fixed assets or to add to the value of existing fixed assets to create future benefits.
Operating expenditure (OPEX)	Expenditure (ongoing) for running a product, business, or system.
Asset	Refers to the collection of tangible and non-tangible assets required to provide a product or service to its customers. Jemena consists of the following Assets: Jemena Electricity Network (JEN), Jemena Gas Network (JGN), Queensland Gas Pipeline (QGP), Eastern Gas Pipeline (EGP), Colongra Gas Pipeline (CGP), ActewAGL and Northern Gas Pipeline (NGP).
Asset Class	A separation of the Assets into smaller manageable components that enable decision-making relating to implementing broader strategies in a meaningful way. Example is Primary Plant or Secondary Plant.
Asset Management Plan (AMP)	The Asset Management Plan provides the optimised plan to manage the assets, understanding the existing and future customer requirements and operating environments, balancing the competing requirements of financial constraints, commercial & business objectives, regulatory requirements, and asset condition (including risk/opportunities). It informs the 7 year operational and capital expenditure and the two-year plan of work.
Asset Management Policy	A short statement that sets out the principles by which Jemena intends to apply asset management to achieve its objectives.
Sub-asset Class	A separation of an asset class into smaller manageable components that enable decision-making relating to implementing broader strategies in a meaningful way. An example is Transformer, Protection & Control relay or DC Supply Systems.

7 APPENDICES

7.1 APPENDIX A - ASSET CRITICALITY ASSESSMENT WORKSHEET (2 PAGES)

ASSET CRITICALITY ASSESSMENT WORKSHEET

ASSET AND BACKGROUND INFORMATION	
Site Name	General
Asset Class	Secondary Plant
Sub-Asset Class	All
Date of Original Assessment	15-May-18
Date of Last Review	21-Aug-18
Reviewed By (where applicable):	

Risk Ref. No.	Description of Asset or Asset Grouping	Description of Risk	Consequence Category (Operational, HSE, Reputation etc.)	Description of Consequences	Current Controls	Criticality Score	Criticality Rating
1	Protection and Control Equipment	Risks associated with running protection control relays to failure, resulting in loss of supply / affecting supply reliability	Operational	**Major** due to potential for loss of electricity supply to >2% customers (6,500) > 24 hours		AC4	High
2	DC Supply System	The risk associated with the loss of duplicated DC supply leading to loss of protection and control schemes.	Operational	**Major** due to potential for: • Total permanent disability (staff or contractors) • Multiple hospitalisations, permanent disability and/or life threatening injuries affecting member(s) of the public		AC4	High
3	GPS Clocks	Failure of the GPS clock time stamp due to age, power supply, loss of satellite synchronisation during a fault. If time stamping is incorrect during a fault, the whole purpose of the GPS clocks funcionality is lost. This compromises the fault investigation because it prevents JEN from finding the root cause(s), resulting in recurrences of a similar fault	Operational	**Minor** due to potential loss of electricity supply to < 1,000 customers up to 6 hours		AC1	Low
4	Communication Network Devices	Failure of network device due to power supply and processor failure under fault and normal conditions.	Operational	**Serious** due to potential loss of electricity supply to >1% of customers (3,000) >3 hours delayed restoration During normal conditions - Risk is considered Minor because a zone substation will still be in operation without communications to the control room.		AC2	Moderate
5	RTU	Failure of a Remote Terminal Unit during a network fault (power supply, processor module, communications module and input or output module) This compromises the fault investigation because it prevents JEN from finding the root cause(s), resulting in recurrences of a similar fault	Operational	**Serious** due to loss of electricity supply to >1% of customers (3,200) up to 3 hrs delayed restoration (worst case a fault occurs on bus) During normal conditions - Risk is considered Minor due to station still in operation even with loss of visibility until attendance to site to rectify		AC2	Moderate
6	Multiplexer	Failure of multiplexers supporting line protection schemes	Regulatory & Compliance / Brand, Reputation & Stakeholders	**Severe** due to: • Regulator requires formal explanations & remedial action plans • Fines or penalties from legal issues, breaches or non-compliances due to loss of redundacy of subtransmission line for more than 8 hours (it is a regulatory requirement for this condition not to exceed 8 hours) which could lead to power loss to multiple zone substations • Significant adverse public attention and/or heightened concern from stakeholders		AC3	Significant
7	iNET Radio & 3G Service	Failure of the iNet radio transceivers or 3G modems due to power supply failure during a fault or normal conditions	Operational	**Severe** due to loss of electricity supply to >1% of customers (3,200) up to 3 hours delayed restoration (worst case a fault occurs on bus) During normal conditions - Risk is considered Minor due to loss of electricity supply to <1,000 customers up to 6 hours delayed restoration (worst case a fault occurs on bus) Likelihood: Rare due to redundant links in the network allowing alternate path for services.		AC3	Significant
8	Communications Cable	Failure of copper supervisory cable or fibre optic cable	Operational	**Severe** due to loss of electricity supply to >1% of customers (3,200) up to 3 hours delayed restoration (worst case a fault occurs on bus)		AC3	Significant

Score	Criticality Rating	Consequence Rating	Description	Consequence Category						
				Finanacial		Operational	Health, Safety & Environment	Employee	Regulatory & Compliance	Brand / Repuation / Stakeholders
				EBITDA / Cashflow	Recoverable Value					
AC5	**Extreme**	**Catastrophic**	Potential disastrous impact on SGSPAA strategies or operational activities. Widespread stakeholder concern / interest.	> 6% of EBITDA (> $50M). Imminent liquidity /cash flow problem – 100% utilisation of undrawn credit facilities & cash at bank.	> 5% or $500M of Recoverable Value of SGSPAA's Assets	Loss of electricity supply to 2 Zone Substations >24 Hrs or >15% Customers (49,000) >24 Hrs. Loss of gas supply to > 20% Customers (220,000). Business interruption for > 30 days (network / pipelines).	1 or more fatalities (staff, contractors or member(s) of the public). Significant destruction of key internal asset or third party property. Harm to the natural environment and/ or culturalheritage that cannot be remediated .	Skill set/ capability of >35% of business critical roles lost within a 6 month period	Major regulatory restrictions and/or govt. interventions. Possible loss of licence to operate. Frequent regulatory or policy violations / breaches Major litigation, with a possibility of punitive damages. Significant fines, prosecutions and jail terms possible.	Sustained and hostile public campaign. Reputation impacted with majority of key stakeholders. Sustained and critical stakeholder criticism.
AC4	**High**	**Major**	Significant impact on SGSPAA strategies or operational activities. significant stakeholder concern / interest.	3-6% of EBITDA ($25M - $50M). Liquidity / cash flow May be adversely affected - 100% utilisation of undrawn credit facilities.	3-5% or $300 - $500M of Recoverable Value of SGSPAA's Assets	Loss of electricity supply to > 2 % Customers (6,500) >24 Hrs. Loss of gas supply to > 1% Customers (11,000). Business interruption for 7 – 30 days (network / pipelines / offices).	Total permanent disability (staff or contractors). Multiple hospitalisations, permanent disability and/or life threatening injuries affecting member(s) of the public. Significant damage to internal assets or third party property. Harm to the natural environment and/ or cultural heritage with remediation difficult (multi-year management).	Skill set/capability of 20 – 35% of business critical roles lost within a 6 month period	Regulatory investigations or govt. review. Some regulatory or policy violations / breaches. Litigation involving significant senior management time. Major fines or penalties and prosecutions possible.	Significant adverse public attention and/or heightened concern from stakeholders. Reputation impacted with significant number of stakeholders. Significant stakeholder criticism/negativity.
AC3	**Significant**	**Severe**	Moderate impact on SGSPAA strategies or operational activities. Moderate stakeholder concern / interest.	1-3% of EBITDA ($8M - $25M). Liquidity / cash flow May be affected – 50% utilisation of undrawn credit facilities.	1-3% or $100- $300M of Recoverable Value of SGSPAA's Assets	Loss of electricity supply > 1% Customers (3,200) > 24 Hrs. Loss of gas supply to > 0.1% Customers (1,100). Business interruption for 1 - 7 days (network / pipelines / offices).	Single permanent partial disability (staff or contractors). Medical aid required for member(s) of the public. Some loss of or damage to third party property. Harm to the natural environment and/ or culturalheritage that can be remediated (<1 year management).	Skill set/capability of 10-20% of business critical roles lost within a 6 month period	Regulator requires formal explanations & remedial action plans. Fines or penalties from legal issues, breaches / non-compliances.	Persistent public scrutiny. Reputation impacted with some stakeholders. Some stakeholder concern/negativity.
AC2	**Moderate**	**Serious**	No material impact on SGSPAA, issues are dealt with internally.	0.1-1% of EBITDA ($1M - $8M). Liquidity / cash flow impact absorbed under normal operating conditions – 25% utilisation of undrawn credit facilities.	0.1-1% or $10-$100M of Recoverable Value of SGSPAA's Assets	Loss of electricity supply to > 1% customers (3,200) > 6 Hrs. Loss of gas supply to > 100 Customers or any contract customer. Business interruption for 1 day (network / pipelines / offices).	Medical treatment injury or lost time injury (staff or contractors). On-site first aid to a small number of member(s) of the public, lost time. Harm to the natural environment and/ or culturalheritage requiring minimal Remediation (at the time of impact).	Skill set/ capability of 5 – 10% of business critical roles lost within a 6 month period	Isolated regulatory or policy violations / breaches. Fines or penalties possible.	Sporadic, adverse media/public attention. Limited adverse reputational impact. Minor stakeholder complaints.
AC1	**Low**	**Minor**	Negligible impact on SGSPAA, issues are routinely dealt with by operational areas.	< 0.1% of EBITDA (< $1M). Negligible impact on liquidity / cash flow.	< 0.1% or $10M of Recoverable Value of SGSPAA's Assets	Loss of electricity supply to <1,000 Customers up to 6 Hrs. Loss of gas supply to > 5 residential customers. Business interruption for a few hours (offices only).	Minimal impact on health & safety (staff, contractors or member(s) of the public). Harm to the natural environment and/ or cultural heritage requiring no active remediation and/or able to self-remediate.	Skill set/ capability of <5% of business critical roles lost within a 6 month period	General regulatory queries. No violations / breaches, fines or penalties.	Negligible media/public attention, reputational impact and/or little or no stakeholder interest.

7.2 APPENDIX B - ASSET OBJECTIVES KPI ALIGNMENT (3 PAGES)

Business Objectives and Targets (by 2025)	ABS Policy Directives	ACS Objectives and KPIs	ACS Strategy to deliver ACS objectives	Performance Assessment
Safety Top quartile industry safety performance	• Never compromising employees', contractors' and the public's safety; • Apply the Jemena risk management approach; and • Facilitate continual improvement in asset safety and performance.	Meet network service levels including safety indicators (annually): • No death or injury[4] to a person (Alert Level: death or injury > 0) • No significant disruption[5] to the community (Alert Level: major disruption > 0) • Secondary Plant initiated fires (Alert Level: ZONE SUBSTATION fires > 0) • Maintain public safety by maintaining ZONE SUBSTATION physical security, visibility and warnings to public	For all assets in the asset class: • Asset Inspection, condition monitoring and maintenance • Asset replacement programs For specific assets: • Provide adequate protection for JEN assets • Protection & Control Online Monitoring	ACS objectives and KPIs are supported through establishment of: **Polices and plans:** - Incident Investigation Process - Electricity Safety Management Scheme (ESMS) **Analysis and reporting:** • Asset performance monitoring • RIN reporting • ESV reporting • Incident investigation reporting • ESMS reporting • OHS&E reporting • Field auditing • ESV audit reports • Budget reporting **Performance review committees:** • Asset performance monitoring • ESMS management • OHS&E These policies, plans, reports and committees are used to assess the performance of the asset to support the delivery of the ACS Objectives and KPIs.
	• Comply with applicable law, regulations, codes and reporting requirements at all times	• Comply with Electricity Distribution Code • Comply with NER requirement • Leverage F-factor scheme • Meet all of JEN's statutory obligations	• Management commitment for Jemena to meet all legal and regulatory obligations • Establishment of ESMS • Audit and compliance programs • Report any serious and other incidents according to the ESV reporting guidelines	

4 Injury to a person means bodily harm requiring or appearing likely to require medical attention

5 Any event that: (i) qualifies for exemption under "S" factor scheme or (ii) results in supply interruption that has significant media interest or (iii) asset failure resulting in significant disruption to vehicle or public transport traffic or (iv) results in interruption to 50,000 customers or 100 MW due to an outage event.

		required under the Electricity Safety Act 1998 • ESMS regulation		
Performance Cost at or below regulatory allowance	Achieve annual targets for Customer reliability/responsiveness: 1. Unplanned System Average Interruption Duration Index 2. Unplanned System Average Interruption Frequency Index 3. Unplanned Momentary Average Interruption Frequency	• Maintain network SAIDI, SAIFI, MAIFI annual targets (monitor monthly performance reports for asset failures) • Maintain the time taken to respond to faults/incidents (Average Dispatch Time, Average Onsite Time) • Complete incident investigations within 20 business days • Complete all scheduled asset inspection and maintenance plans within documented intervals • Review Electricity Secondary Plant ACS at least every 3 years	• Identification and timely replacement of end-of-life secondary plant assets • Monthly performance monitoring • Incident investigations and follow up actions to improve performance of secondary plant assets • Deliver secondary plant asset replacement program in line with the budget • Deliver secondary plant asset inspection, condition monitoring, checking & testing programs as per sub-class strategies	
	• Ensure capital program for each JEN asset is within budget while also delivering planned or equivalent scope of work	• Successfully deliver asset replacement and/or reinforcement (as applicable) program • Deliver asset replacement	• Jemena portfolio management • Annual review of projects to be included in COWP • Business case approval process	

		programs to agreed budget		
Customer Cost per customer trending downward, with no deterioration in-service levels	• Incorporate Customer expectations and outcomes into our Asset Management plans and documents • Ensure Customer service levels and customer obligations are met	• Meet all above mentioned safety and performance measures • Engage with customer focus groups • Perform Regulatory Investment Tests for Electricity Primary Plant Investment (RIT-D) • Review equipment and design specification to improve procurement options to reduce asset life cycle costs	• Attendance at customer forums to obtain feedback • Review and consideration of RIT-D submissions • Review of relevant design, testing and commissioning standards within documented intervals	In addition to the above, ACS objectives and KPIs are supported through establishment of: ○ Customer Charters ○ Customer Focus Groups ○ Regulatory Investment Tests ○ Customer Relations Team
Growth Additional growth value created over base business	• Support business development projects	• Procure, build, maintain and dispose of, any new assets required due to growth, in accordance with this ACS.	• Project Management Methodology • Demand forecasting and Customer Initiated Capital (CIC) forecasting methodologies	ACS objectives and KPIs are supported through establishment of: • Timely delivery of customer projects and network augmentations • Meeting budget requirements ○ Budget reporting ○ Jemena Portfolio Management Governance
People Employee engagement performance	• Improve the linkage of people development activity to succession planning needs and skills gaps in Asset Management	• Identify people development opportunities to address any skill gaps in Asset Management • Promote continual improvement initiatives through training, knowledge sharing and mentoring	• Employee engagement surveys • Employees are encouraged to contribute to development of improvement initiatives (forums, management updates etc.) • Performance Management and Development Plans • Secondments and rotation opportunities • Training and development programs and courses • Succession Planning	ACS objectives and KPIs are supported through review of: • Employee Engagement Survey Results • Performance reviews occur bi-annually including regular management feedback.

7.3 APPENDIX C – PROTECTION & CONTROL – HISTORY OF CAPEX REPLACEMENT INITIATIVES (2 PAGES)

Year	Quantity	Description	Reason for replacement
2008	All 66kV Line protection schemes	KTS-ES-BY-KTS	Replaced the entire aged / deteriorated 66kV line protections with duplicated Differential protection scheme.
2009	All 66kV Line protection schemes	WMTS-FE-WMTS	Replaced the entire aged / deteriorated 66kV line protections with duplicated Differential protection scheme.
2009	All 66kV Line protection schemes	TTS-CS-CN-TTS	Replaced the entire aged / deteriorated 66kV line protections with duplicated Differential protection scheme.
2009	All Secondary Equipment	NT	As part of NT redevelopment project.
2011	All Secondary Equipment	HB	As part of HB switchgear replacement project.
2012	All 66kV Line protection schemes	KTS-AW-PV-KTS	Replaced the entire aged / deteriorated 66kV line protections with duplicated Differential protection scheme.
2012	All Secondary Equipment	PV	As part of PV augmentation project.
2012	All 66kV Line protection schemes	TTS-NH-NEI-WT-TTS	Replaced the entire aged / deteriorated 66kV line protections with duplicated Differential protection scheme.
2013	All Secondary Equipment	YVE	As part of the YTS redevelopment project
2015	All Secondary Equipment	EPN	AS part of the EPN redevelopment project.
2016	All 66kV Line protection schemes	HB-TSTS and HB-Q	Replaced the entire aged / deteriorated 66kV line protections with duplicated Differential protection scheme.
2017	All Secondary Equipment	AW	Replaced the entire aged / deteriorated protection and control relays at AW.
2017	22kV Feeder Protections at BLTS	BLTS	Replaced the entire aged / deteriorated protection and control relays at BLTS.

2018	All Transformer Protection & Control relays and new 22kV Line Differential Protections	NS	Replaced all existing Transformer protection and control relays at NS. Also new 22kV Line Differential protection relays have been installed at NS.
2018	All Transformer Protection & Control relays and new 22kV Line Differential Protections	FF	Replaced all existing Transformer protection and control relays at NS. Also new 22kV Line Differential protection relays have been installed at NS.
2018	All Transformer protection relays, BUEF and Cap Banks relays.	ES	No.1 and No.2 Transformer Protections are beyond their life. These relays are CDG relays without real-time monitoring feature. Also the Cap Bank Voltage Leakage relays need replacing.