Jemena Electricity Networks (Vic) Ltd

Replace Footscray East (FE) Zone Substation Switchgear

2020 and 2021 Business Case

BAA-RSA-800111

Public

31 January 2020

An appropriate citation for this paper is:

Replace Footscray East (FE) Zone Substation Switchgear

Authorisation

Name	Job Title	Date	Signature
Prepared by:			
Primary Plant Engineer			
Technical Endorsed by:			
Asset Engineering Manager			
Budget Endorsed by:			
Electricity Asset Investment Manager (acting)			
Approved by:			
General Manager Asset Management (acting)			

History

Rev No	Date	Description of changes	Author
1	13/06/2019	Original Issue	Primary Plant Engineer

Owning Functional Area

Business Function Owner:	Asset Management - Electricity Distribution

PREFACE

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

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1. EXECUTIVE SUMMARY

Paper Summary

- The switchgear at Zone Substation FE (Footscray East) is at risk of failure due to its poor condition and poses serious safety and security of supply concerns.
- To manage the risks this project involves replacement of two 22kV buses, one 66kV bus tie circuit breaker, one 66kV line circuit breaker, DC supply system and 66kV insulators, together with protection and control schemes.
- The switchgear replacement project will also include the replacement of 4 of 5 FE 22kV feeder exit cables which are 52 years old paper lead cables and have had failure history.
- The project will be completed during 2020 and 2021 at a cost of $5,803K (total project cost, real $2019).

1.1 BUSINESS NEED

Zone Substation FE (Footscray East) has two 66kV/22kV power transformers rated at 30MVA and 33MVA, two 66kV Bus Tie circuit breakers (one is 66kV AEI LG4C), two 22kV buses and five 22kV feeders supplying around 14,329 Jemena customers.

The two indoor 22kV metalclad buses and associated circuit breakers manufactured by Metropolitan Vickers type SB14 are estimated to be 82 years old and their condition have degraded to a point where they pose material risks to employee safety, reliability and security of customer supply. Identical switchgear is also installed at Zone Substation FW (Footscray West), and is unique to Jemena. No other Australian electricity business has this switchgear installed. A Business Case to replace the switchgear at Zone Substation FW (Footscray West) will be prepared separately to this paper. The new switchgear will conform to current Australian Standards and will mitigate safety concerns, maintain reliability and security of customer supply.

There are Twelve current issues associated with the Zone Substation FE assets as described below:

1. Condition monitoring tests conducted on the indoor 22kV buses at FE indicates that Partial Discharge (PD) is occurring. The presence of PD will ultimately cause the insulation to fail catastrophically. This is the critical issue. The switchgear has been subjected to condition monitoring tests in 2008 as well as 2018. The results clearly show further degradation of the primary insulation.

2. The switchgear is non-compliant with current switchgear standards for electrical arc fault containment. This presents a health and safety risk to Jemena personnel, due to the active PD at near service voltage. In the event that the insulation fails, the resulting electrical arc and pressure wave will not be contained within the switchgear, and consequently the risk to employee health and safety is elevated. This is a critical issue.

3. The switchboard is obsolete and the lack of serviceable spares necessary to recover from a catastrophic failure will impact on supply reliability to Jemena customers. This switchboard is no longer supported by the manufacturer and spare components are no longer available. This is a critical issue.

4. The switchgear has a history of oil leaks from the circuit breaker and internal isolator compartments. This is not an issue that is driving the replacement of the switchgear however it does require elevated levels of operating expenditure to manage.

5. Maintenance of the 22kV bus and associated circuit breakers requires special procedures which are unique to this type of switchgear. The task is managed with a work procedure, however it exposes field personnel to

increased safety concerns and it will be beneficial to replace the switchgear to mitigate the safety risk. Although this is a non-standard design, this is not a critical issue.

6. The internal 22kV isolators and earthing switches are immersed in oil and do not require maintenance to date. However considering the age of the switchgear, their condition will need to be assessed in the future and this will be a costly maintenance activity. This is not a critical issue.

7. 22kV Outdoor Transfer bus: There are known defects associated with pin and cap 22kV insulators which are prone to failure. There have been two serious incidents within other electricity business. In one instance a 22kV insulator sheared off and the HV dropper came in contact with a person below. This is not an issue that is driving the replacement of the indoor switchgear, however the new proposed 22kV switchgear provides an opportunity to the remove outdoor 22kV transfer buses together with the associated safety risk. See Appendix E for further details: 22kV Pin and Cap insulator Failure.

8. The 66kV Bus Tie Circuit Breaker represents a family of breakers with history of mechanical failure and catastrophic bushing failures. This CB Type LG4C is no longer supported by a manufacturer and spare components are no longer available. This is also a critical issue.

9. Outdoor 66kV insulators: The 66kV insulators at FE were observed to have significant electrical discharge on most of the buses and disconnect switches. This is an issue causes Radio Frequency Interference (RFI) and ultimately may result in insulation failure. This is the main issue driving the replacement of the 66kV insulators, and an opportunity exists to undertake this work at the same time as the 22kV switchgear replacement.

10. The DC supply system is deteriorated and at risk of failure. Most batteries at FE are beyond their design life (15 years), have deteriorated and are failing. This is a critical system as it is used to supply auxiliary power to protection relays, control and communication circuits, and to trip/close HV circuit breakers. When a network fault occurs and if the battery system has failed, people safety would be at risk, there is risk of damage to assets and risk of loss of electricity supply to customers, apart from impacting Jemena brand and reputation.

11. The external FE Zone Substation security fence requires replacement at certain sections. Parts of the existing security fence are damaged or deteriorated beyond repair, and do not provide the required security (as set out in JEN's Primary Design Manual) for a high criticality zone substation site.

12. Analysis of the performance of HV paper lead cables has shown a fast-increasing trend of failure in the last three years. JEN's investigation of the cables at Zone Substation FE has identified significant deterioration. which means the barriers from mechanical damage and moisture have been weakened, risking electrical failure. Failure at the cable head not only cause supply interruptions to customers but also poses a safety risk to the public as shattered porcelain could cause death or serious injury to the public or cause damage to nearby third party property. There also have been many supply interruptions to customers due to animal strikes on the feeder exit isolators, for which animal proofing is not available.

Given the switchgear replacement works proposed for Zone Substation FE, there is an opportunity to concurrently address these issues to realise project management and delivery efficiencies.

The following options to address the issues have been considered.

1. Do nothing;
2. Increased maintenance and monitoring;
3. 22kV and 66kV Switchgear refurbishment;
4. Transfer load and
5. Replace switchgear

The option of a non-network solution (e.g. demand management and/or embedded generation) would not address the asset condition risks at FE zone substation.

A comparison of the twelve options listed above and the issues they address is shown in Table 1-1.

Table 1-1: Options Analysis

Condition Issue	Option 1 Do Nothing	Option 2 Increased Maintenance and Monitoring	Option 3 Refurbishment	Option 4 Load Transfer (Build a new Zone Substation)	Option 5 Replacement
Issue 1 Switchgear Condition	○	○	○	●	●
Issue 2 Non ARC fault Containment	○	○	○	●	●
Issue 3 Lack of Spare Parts	○	○	○	●	●
Issue 4 Insulation Oil Leaks	○	◑	●	●	●
Issue 5 Nonstandard Test procedures	○	○	○	●	●
Issue 6 Maintenance Intensive	○	○	◑	●	●
Issue 7 22kV Insulators	○	○	○	●	●
Issue 8 66kV CB’s	○	○	◑	●	●
Issue 9 66kV Insulators	○	○	○	●	●
Issue 10 DC Supply	○	○	○	●	●
Issue 11 Security Fence	○	○	○	●	●
Issue 12 Feeder Cables	○	○	○	●	●
Technically Viable	○	○	○	◑	●

●	Fully addressed the issue
◕	Adequately addressed the issue

◑	Partially addressed the issue
○	Did not address the issue

1.2 RECOMMENDATION

The replacement of the switchgear is recommended and consistent with regulatory requirements in section 6.5.7 of the National Electricity Rules, and section 3.1 of the Electricity Distribution Code. The two indoor 22kV metalclad buses and associated circuit breakers manufactured by Metropolitan Vickers are estimated to be 82 years old, and their condition has degraded to a point where safety, reliability and security of customer supply will be affected.

It is recommended that Option 5 be adopted and the two 22kV metalclad buses, the 1-2 66kV bus tie CB and 66kV insulators be replaced with new modern equivalents and installing them to current standards, together with protection and control schemes. In addition a new WMTS No.1 line CB will be installed. The main switchroom and control room building built in 1967 will be utilised to accommodate the new 22kV switchgear and protection equipment, rather than construct a new separate building. The building has various defects that will be repaired, and in addition will be made compliant to current building standards.

This option is considered prudent, has a positive net present value and is the preferred option, and will address all know issues identified in Section 2.1. The new switchgear will conform to current Australian Standards and will mitigate safety concerns and allow JEN to maintain reliability and security of supply to customers in the FE supply area.

The total cost of this option is estimated to be $5,803K (total project cost, real $2019) and the project would commence in 2020. The project would be commissioned by 2021.

The replacement of the switchgear is recommended and consistent with the capital expenditure objectives set out in section 6.5.7 of the National Electricity Rules, and the requirements of section 3.1 of the Electricity Distribution Code.

1.3 REGULATORY CONSIDERATIONS

The objective of the project is to determine the most appropriate strategy to mitigate safety risks and maintain the reliability of supply to customers in the FE supply area in light of the identified condition issues with equipment at FE. This strategy must be consistent with other JEN strategies and plans and the project must comply with associated regulatory requirements including the National Electricity Rules (in particular clause 6.5.7) and the Victorian Electricity Distribution Code.

Five options will be explored in Section 3.3 of this document to identify the best possible option. The options will be benchmarked against the risk assessment from Appendix I to ensure the health, safety and supply issues are addressed. Fundamentally risk, cost and value will be the primary drivers and the option which maximises the net benefit to customers over the long-term will be recommended.

Since this project satisfied the RIT-D threshold, JEN published a RIT-D Stage 1: Non-network Options Screening Report for this project on 1 February 2019[1]. As part of the report, JEN assessed potential network and non-network options to address the identified need. The analysis demonstrated that there are no combinations of non-network options, or non-network and network options, that are likely to adequately meet the criteria that would necessitate the production of a non-network options report. Hence as per RIT-D process, JEN will conclude this

[1] https://jemena.com.au/documents/electricity/fe-switchgear-condition_rit-d_non-network-options.aspx

project's RIT-D by publishing its final project assessment report summary as part of its Distribution Annual Planning Report (**DAPR**) 2019.

1.4 FINANCIAL INFORMATION

1.4.1 FORECAST EXPENDITURE AND BUDGET SUMMARY

This business case proposes a total investment of $5,803K (total project cost, real $2019) and requires Managing Director's (Band B) approval under the SGSPAA DFA Manual, Annex 3.

This project is required to be commissioned by the end of 2021.

Table 1-2**Error! Reference source not found.** presents a summary of the business case and budgeted value for this project, as well as the overhead allocations applied.

Table 1-2: Project Budget Information

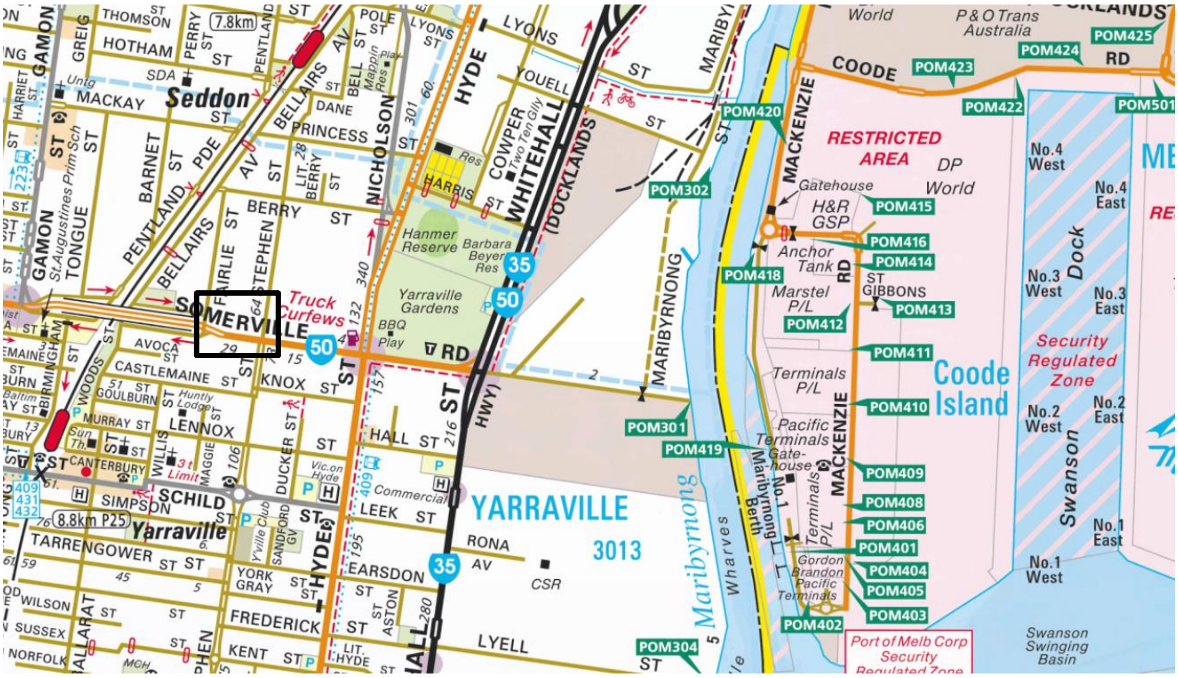
Business Case Spend	Total ($'000s, $2019)
CAPEX	4,588
Overhead Recovery	1,215
Total Business Case Value	**5,803**

2. BACKGROUND

The purpose of this document is to set out the business case for the Zone Substation FE (Footscray East) switchgear replacement project, including its alignment with JEN's Electricity Primary Plant Asset Class Strategy for Zone Substations.[2]

Zone Substation FE was commissioned in 1967 and is located to the west of the Melbourne CBD in Somerville Road, Seddon (Melways ref:42 C8) as shown in Figure 2–1. It supplies 14,329 customers in the Footscray, Footscray East, Yarraville and Spotswood and areas. The customer split based on customer numbers is 89.5% residential, 10.3% commercial and 0.2% industrial, and includes major customers such as the Western General Hospital.

Figure 2–1: Location of Zone Substation FE (Footscray East)



Zone Substation FE (Footscray East) consists of two 66kV/22kV power transformers rated at 30MVA and 33MVA and has five 22kV feeders which supply 14,329 Jemena customers. Refer to Appendix F for the Single Line Diagram.

The two indoor 22kV metalclad buses and associated circuit breakers (CB) at Zone Substation FE are estimated to be 82 years old. They were manufactured by Metropolitan Vickers (type SB14) in 1937 rated at 20kV, 25 cycles. The switchboard was tested against the SECV 50-51/100 specification to operate at 22kV, 50 Hertz. It is understood that this switchgear was originally purchased for the Newport (coal fired) Power Station and remained as a spare unit in the SECV store at Brooklyn. The circuit breakers have not been designed to be racked out and instead have been fitted with internal HV isolators and earth switches. The busbars consist of a condenser type bushings, which are located externally to the circuit breakers. This switchgear was installed at FW in 1967.

Refer to Appendix F for the Single Line Diagram.

[2] See Appendix A – ELE AM PL 0061 Primary Plant Asset Class Strategy.

Figure 2–2: The existing general layout of Zone Substation FE

Asset Details

The 22kV switchgear installed at FE is briefly described in Table 2-1 and Figure 2–3. This switchgear is unique to JEN's Zone Substations FE and FW, and is not installed anywhere else in Australia. Enquiries made to the UK did not reveal any information regarding this type of switchgear. The switchgear is metalclad enclosed consisting of a fixed CB compartment and internal isolators and earth switches, immersed in a thick insulating oil. The 22kV buses are constructed in sections underneath the checker plate floor, and enters each CB compartment. Each busbar section consists of a bushing which enters a tee connection box and is filled with thick insulating oil.

Table 2-1: FE Switchgear Details

Designation	Make	Type	Voltage	Current	SECV Spec No.	Year of Manufacture
No.1 22kV Bus	Metropolitan Vickers	SB14	22kV	1,200A	50-51/100	1937
No. 2 22kV Bus	Metropolitan Vickers	SB14	22kV	1,200A	50-51/100	1937

Figure 2–3: FE 22kV Switchgear

The annual maximum demand at FE occurs in summer and is forecasted to be 39.4MVA in summer 2019/20. Summer refers to the period of 1 October of the previous year to 31 March. The N-1 station cyclic rating is 30.5MVA in summer. The actual and forecast maximum demand (10POE[3]) for the period 2017 to 2025 is shown in Table 2-2[4].

Table 2-2: FE Station Loading

Station Loading	Actual		Forecast Demand (10POE[2])						
	2017	2018	2019	2020	2021	2022	2023	2024	2025
Summer MVA	32.2	33.8	38.9	39.4	40.5	42.8	44.6	44.9	45.3

There have been 21 recorded defects associated with the FE switchgear (as captured) in Jemena's Maintenance Management System. In addition, 45 defects have also occurred on the same model switchgear at zone substation FW. Some of these defects are shown in Table 2-3. The most serious defect was associated with a high resistance connection, and melted HV contact on feeder FW13 CB. Refer to Appendix B for details. This defect was identified during other work by chance, and had the potential to result in a catastrophic failure. In general, maintenance programs do not always prevent failures occurring, as they can develop after the asset has been maintained. The most chronic and ongoing defect for the FE switchgear relates to oil leaks, which is deteriorating at an increased rate.

3 10 PoE maximum demand is the level of annual demand that is expected to be exceeded one year in ten.

4 The forecast loading estimate is derived from the Distribution Annual Planning Report 2017, which can be accessed here.

Table 2-3: FE Switchgear Defect History

Date	CN Asset	Defect	Remedy
2002	FDR FE 9 CB	CB Trip Free	Investigate, repair
2004	FDR FE 1, 5, 8, 1-2 22kV BT CB	Low Oil	Investigate, oil top up, and/or tightened bolts
2005, 2009	OOS CB C	Leaking Oil	Investigate, oil top up, and/or tightened bolts
2008, 2014	FDR FE 9 CB	Leaking Oil	Investigate, oil top up, and/or tightened bolts
2009	FDR FE 5 CB	Failed to Operate	Investigate, repair
2009	FDR FE 1 CB	Low Oil	Investigate, oil top up, and/or tightened bolts
2009	FDR FE 8 CB	Low Oil	Investigate, oil top up, and/or tightened bolts
2009, 2010	1-2 22kV VT CB	Low Oil	Investigate, oil top up, and/or tightened bolts
2010 (x2)	FDR FE 5 CB	CB Trip Free	Investigate, repair
2010	NO.1 TRANS 22KV CB	Leaking Oil	Investigate, oil top up, and/or tightened bolts
2012	FDR FE 5 CB	CB Trip Free	Major repair
2012 (x2), 2019	FDR FE 5 CB	CB Trip Free	Investigate, repair

The 66kV switchgear installed at FE is briefly described in Table 2-4 and Figure 2–4.

Table 2-4: FE 66kV Bus Tie CB Details

Designation	Make	Type	Voltage	Current	SECV Spec No.	Year of Manufacture
1-2 66kV Bus Tie CB	AEI	LG4C	66kV	1,200A	64-65/199	1965
66kV buses	SECV	N/A	66kV	800A	N/A	1967

Figure 2–4: FE 66kV Bus Tie CB and 66kV insulators

There has been one recorded defect on 1-2 66kV bus tie circuit breaker where the 66kV bushing was replaced, and there are records of this type of CB with a history of defects and catastrophic failures.

The 22kV Transfer Bus installed at FE is briefly described in Table 2-5 and Figure 2–5.

Table 2-5: FE 22kV Transfer Bus Details

Designation	Make	Voltage	Current	SECV Spec No.	Year of Manufacture
22kV Transfer Bus and connections	SECV	22kV	~400A	N/A	1967

Figure 2–5: FE 22kV Transfer Bus

There have been two recent incidents associated with the failure of 22kV pin and cap type insulators within Victoria (Refer to Appendix E) as follows:

6. In circumstances similar to the arrangement in Figure 2–5, an insulator had sheared from the pin, and resulted in the bus dropping to 1m above ground level. The bus remained alive and was found by an employee.
7. An isolator was opened using a HV switch stick when an insulator had sheared from the pin. The live conductor then fell onto an employee's shoulder.

2.1 ASSET RISK ANALYSIS

2.1.1 ASSET CONDITION

Nine current issues associated with the FE assets have been identified and are discussed below:

1. **Condition monitoring tests conducted on the indoor 22kV buses at FE indicates that partial discharge (PD) is present above service voltage. This indicates that insulation degradation has occurred. The same switchgear at FW is also showing signs of insulation failure. The condition monitoring tests conducted on the indoor 22kV buses at zone substation FW indicates that PD may be present during normal operating conditions. The damage due to PD cannot be stopped or reversed and its behaviour cannot be predicted. Over voltage excursions due to lightning strikes on the network or switching surges can accelerate the insulation degradation further. This will increase the level of PD. The presence of PD will continue to degrade the insulation which will ultimately cause the insulation to fail catastrophically. This is a critical issue. The switchgear has been subjected to condition monitoring tests in 2008 as well as 2018. The results clearly show further degradation of the primary insulation.**

The 22kV switchgear at Zone Substation FE are subject to a condition based monitoring regime which is detailed in Appendix A (ELE AM PL 0061 Primary Plant Asset Class Strategy), with test reports provided in Appendix C.

These CBs are currently 82 years old and no longer supported by the manufacturer. Although some circuit breakers/switchboards have continued to operate satisfactorily for over 70 years, a circuit breaker/switchboard is generally considered to be approaching the end of its useful life after 50 years due to its level of mechanical wear, lack of spare parts, insulation degradation and non-compliance to modern arc fault containment safety standards.

The current condition summary for the FE switchgear is shown in Table 2-6.

Table 2-6: FE 22kV Switchgear Condition Summary

Insulation Test	No.1 22kV Bus	No.2 22kV Bus
Insulation Resistance (IR)	Good	Good
Dielectric Dissipation Factor (DDF)	Poor – Initiate replacement	Fair – Initiate replacement
Partial Discharge (PD)	Poor – Initiate replacement	Fair – Initiate replacement
Polarisation Index (PI)	Poor – Initiate replacement	Fair – Initiate replacement

The dielectric dissipation factor of the FE 22kV switchgear is considered Poor when compared to the switchgear at FW. This indicates the insulation has absorbed moisture over time and increased leakage current. Both buses on FE switchgear show about 2-3 times higher leakage current. The PI (polarisation index) results also support the insulation deterioration with low insulation resistance results (PI below 1.5). However the PD test results from 2018 show that PD is present above service voltage and considered to be Poor due to its magnitude and increase from previous test conducted in 2008.

The PD levels for new HV plant is typically less than 50pC, which is consistent with good industry practice. PD measurements are used to detect defects in HV insulation in either new or aged HV plant. Experience shows that PD has led to a progressive degradation in the dielectric strength of the insulation. It should be noted that the PD activity recorded during the testing is only a snapshot in a time. PD sources could be changing in activity over time and also changing under different atmospheric conditions.

The PD results are based on the PD activity at time of test. In theory and most of the time in practice, the higher the PD level the closer the asset is to failure. However, there are several factors that can affect how close the asset is to failure (a higher reading does not necessarily mean it will fail before a lower reading). The carbonisation of tracking, distance of PD source to discharge phase/earth, atmospheric conditions, inception/extinction voltages, system 'events', age of equipment, etc. will all affect the PD activity over time. It is important to remember that the assets with active PD will fail at some point of time, but predicting the time of failure is not an exact science. It is also very important to consider the equipment behaviour, historical events (around the world), risk factors, etc.

For solid insulation, acceptable limits of 10 pC are stated in AS 62271.200-2005 HV Switchgear and Control Gear.

Zone substation FE: The PD inception and extinction level for the No.1 22kV Bus was measured at 16.0kV and 14.0kV respectively. The results for the No.2 22kV bus is 18.0kV and 16.0kV respectively. Although the phase to ground operating voltage is nominally 12.7kV, and PD levels do not appear during normal operating conditions there is a risk of a phase to ground fault sometime in the future as the insulation degrades further. See Figure 2–6 and Figure 2–7 below. The PD levels above service voltage levels range from 20pC to 628pC, which is above industry and Australian Standards (AS 62271 series).

Zone substation FW: The PD inception and extinction level for the No.1 and No.2 22kV Buses was measured at 16.4kV and 14.3kV respectively. Since the phase to ground operating voltage is nominally 12.7kV, this indicates PD may appear during normal operating conditions and there is a risk of a phase to ground fault. See Figure 2–8 below. The PD inception and extinction level for the No.3 Bus Red Phase was measured at 14.0kV, and 9.5kV respectively. This indicates PD may appear during normal operating conditions and there is a risk of a phase to ground fault. See Figure 2–9 below.

Metro Vickers SB14 22kV circuit breakers installed at Zone Substation FE are also showing signs of age-related deterioration. During recent condition monitoring tests they exhibited PD activity which is a sign of degraded insulation. PD is an electrical discharge which occurs in the voids within the insulation and results in irreversible damage due to carbon build up in the voids.

This will increase the level of PD greater than the last test report. In reference to Figure 2–6 below, as the test voltage is increased as shown on the 'x' axis, the PD levels increase rapidly on certain phases. Over voltage excursions above network voltages levels can occur for short durations as a result of lightning strikes on the network or switching surges. In addition when feeder faults occur, healthy phase voltages increase to line voltages (22kV nominal) due to the Neutral Earthing Resistor effect. These events can accelerate the insulation degradation further, and PD levels can then increase when measured at normal system voltage levels. This will increase the level of PD greater than the last test report, and increase the risk of electrical flashover as the asset ages further.

The presence of PD will continue to degrade the insulation which will ultimately cause the insulation to fail catastrophically as a result of a power arc resulting in equipment damage beyond repair and health and safety risks. Although the early onset of PD can be detected, the damage cannot be stopped or reversed.

These test results in 2018 represents a family of switchgear MV type SB14 which is 82 years old and showing clear signs of insulation that has a higher risk of failure under normal operating voltage. Not all of the associated SB14 CB's have been tested, and this may represent a further risk to insulation failure.

Figure 2–6: FE No.1 22kV Bus Partial Discharge measurements

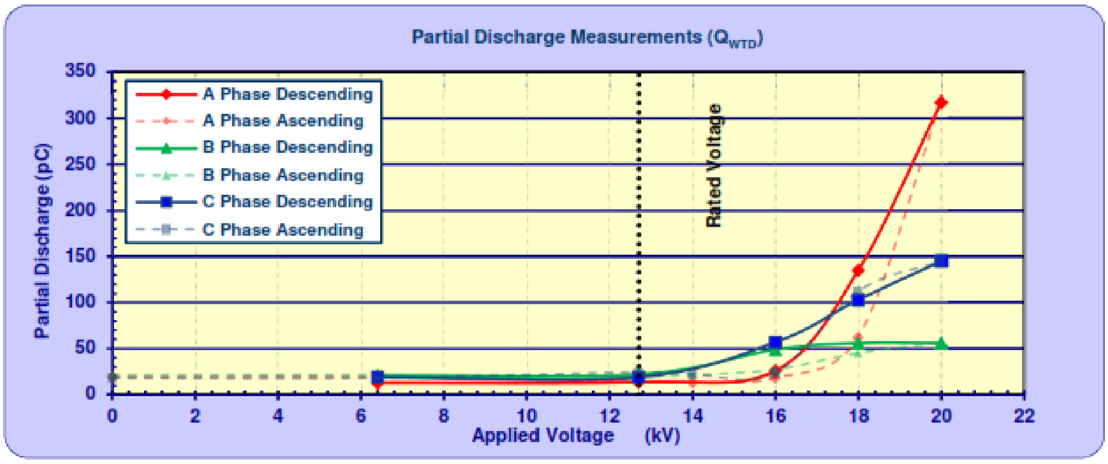


Figure 2–7: FE No.2 22kV Bus Partial Discharge measurements

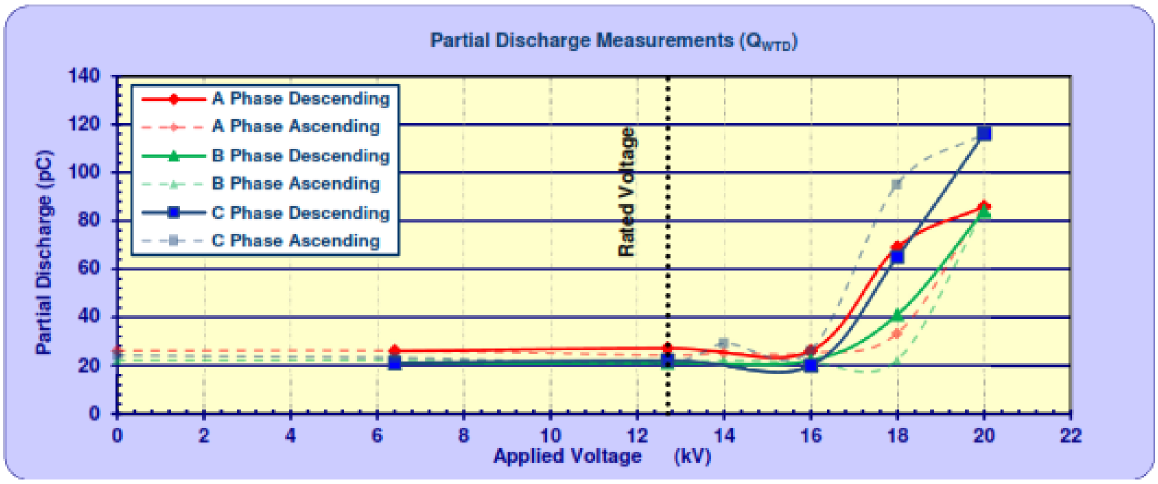


Figure 2–8: FW No.2 22kV Bus Partial Discharge measurements

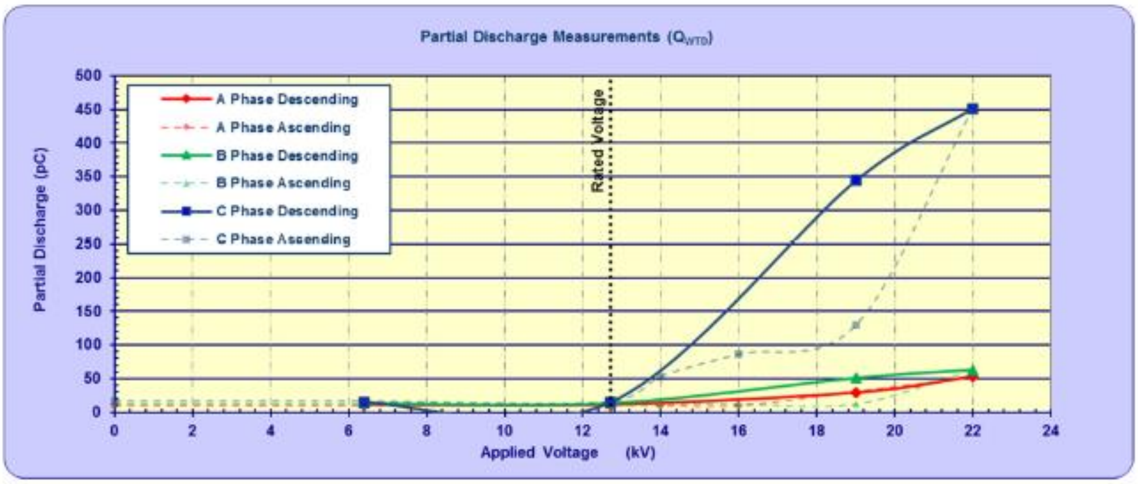
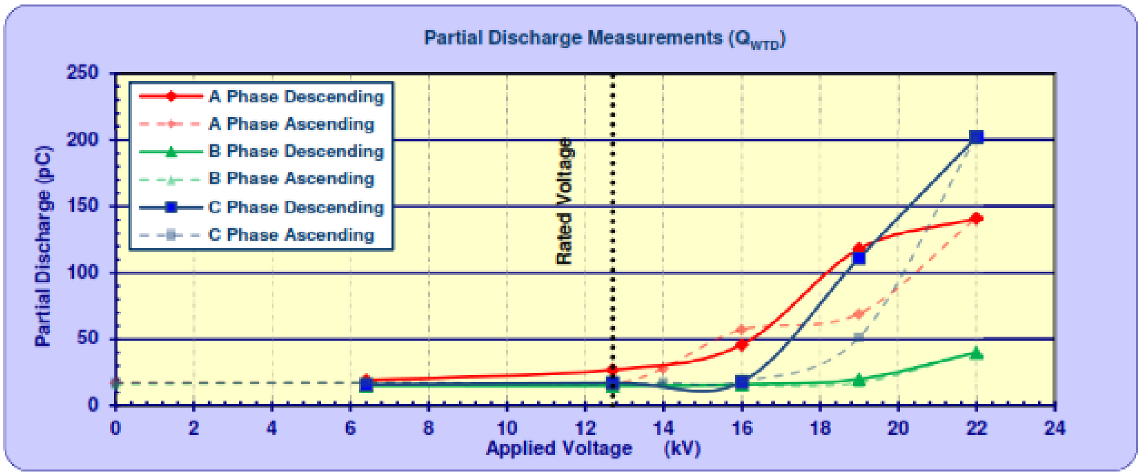


Figure 2–9: FW No.3 22kV Bus Partial Discharge measurements



In addition, the circuit breakers associated with the 22kV indoor buses have a history of issues. The extent of the defects relating to mechanical faults is progressively becoming more serious as the assets age well beyond their economic life. The associated CB mechanisms are worn and on occasions fail to remain closed (Trip Free). Mechanism components have been repaired by welding but this had proven to be a short term solution.

2. **The switchgear is non-compliant with current switchgear standards for electrical arc fault containment standards. This presents a health and safety risk to Jemena personnel, due to active PD at near service voltage. In the event that the insulation fails, the resulting electrical arc and pressure wave will not be contained within the switchgear, and consequently the risk to employee health and safety is elevated. This is a critical issue.**

The switchgear in not compliant with current Australian Standards AS 62271 series (safety requirements), and the circuit breakers only have oil discharge vents to the outdoor switchyard. In the event of a bus or circuit breaker fault, the over pressure will cause the metalclad housing to rupture, releasing gas pressure and hot oil which is potentially a fire risk.

Such an event can occur due to over voltage excursions due to lightning strikes on the network or switching surges which can accelerate the insulation degradation further. This will increase the level of PD greater than the last test report.

New switchgear is designed and type tested to AS62271.200 to provide a safe work place for personnel and reduce consequential damage.

3. **The switchboard is obsolete and the lack of spares necessary to recover from a catastrophic failure may impact supply reliability to customers in the FE supply area. This switchboard is no longer supported by its manufacturer and spare components are no longer available. This is a critical issue.**

The most serious defect experienced at FE was associated with a high resistance connection, and melted HV contact on feeder FW13 CB. Refer to Appendix B for the investigation report. An operator noticed the CB to be operating at a slightly higher temperature with his hand. The CB was immediately taken out of service. An investigation was initiated and repairs completed. The fixed contact cluster was replaced as they were damaged by heat beyond repair. This failure is not readily detectable and there is a risk of catastrophic failure in the future affecting employee safety. The extent of the damage may render the repairs as uneconomical in the future. The costs incurred to repair this single fault is $12k.

Spare busbar bushings and spare circuit breaker components are limited and in most cases non-existent. Repairs have been performed by welding components to renew wearing surfaces. This is not a long term solution. Circuit breakers contacts have been re-engineered and however there are no detailed drawings available to restore the components back to original condition. The busbars are paper Bakelite bushings and the limited spares may not be in a serviceable condition. Performing repairs following a catastrophic failure will be difficult and may not be possible with the existing assets. This lack of availability of spares and manufacturer support would likely mean that customers in the FE supply area would experience significantly prolonged outages while replacement switchgear was constructed, in the event of a catastrophic failure.

4. **The switchgear has a history of oil leaks from the circuit breaker and internal isolator compartments. This is not an issue that is driving the replacement of the switchgear however it does require elevated levels of operating expenditure to manage.**

The incidence of oil leaks appears to be becoming more frequent. To date the repairs have involved tightening bolts, however gaskets have now been compressed to the limit and costly replacement will be incurred in the future. In a case of an oil leak this can cause a flashover inside the switchgear and damage the equipment. Due to its properties and low flash point of the oil the fault may result in a fire which will affect adjacent equipment and building. The oil leaks also present a slip hazard and in some cases may be contaminated with PCBs which represent an environmental hazard.

Several oil leaks have been repaired to date by tightening bolts. Gasket replacements will be necessary in the future. An added complication is the unique insulating oil used within the isolator compartments. The oil (Penetrol) has a very high viscosity. The gasket replacement cost per CB is estimated to be $10k. Total direct cost for 11 CB's x $10k = $110k. The rough cost estimate also includes the removal and disposal of the asbestos rope around the gaskets.

In March 2013 the field crew advised that the CBs were leaking oil from either the bus or the feeder isolator compartment. Subsequently, repairs were undertaken and while the oil leaks have slowed they haven't completely stopped. The CB's will need to be continually monitored until their replacement. Delays in the replacement of the asset will require further investment to replace gaskets.

5. **Maintenance of the bus and circuit breakers requires special procedures which are unique to this type of switchgear.**

As FE and FW are the only zone substations where this type of switchgear is used, maintenance of the bus and circuit breakers requires special procedures to maintain safety of the personnel working on them. Measuring switchgear insulation requires the insertion of special test probes into HV compartments, and removal of earthing links which may be hazardous if procedures are not followed. Although this is a non-standard design, this is not a critical issue and is currently managed with work procedures, however it exposes field personnel to increased safety concerns and it would be beneficial to replace the switchgear to mitigate the safety risk.

6. **The internal 22kV isolators and earthing switches are immersed in oil and maintenance costs will increase in the future. This is not a critical issue.**

The internal 22kV isolators and earthing switches are immersed in oil and maintenance has not been required to date, however considering the age of the switchgear, their condition will need to be assessed in the future and this will be a costly maintenance activity. This work can be undertaken with gasket replacement. An added complication is the unique insulating oil used within the isolator compartments. The oil (Penetrol) has a very high viscosity. The additional cost to maintain the internal oil immersed isolators, above the cost to replace the gaskets is estimated to be 11 CB's x $10k = $110k.

7. **The 22kV Outdoor Transfer bus are pin and cap 22kV insulators, a type with design deficiencies that can lead to insulator failure in service, posing a safety risk to JEN personnel.**

These insulators also consist of a galvanised steel pin cemented into the porcelain and over time as moisture corrodes the pin, the expansion of the rust caused the porcelain to crack and shear. Although various means are used to detect a possible failure such as visual inspection, maintenance and off line PD detection, this defect may still remain undetected until an isolator is operated and the insulator shears off completely. There have been two serious incidents within other electricity businesses with this type of insulator. Pin and cap type insulators have generic design deficiencies that can lead to insulator failure in service.

In 2011 a pin and cap insulator failed in a Victorian electricity network. The failure caused the insulator to separate from its support structure, resulting in a bus isolator together with the pin from the insulator and the tubular bus being left unsupported. The isolator and pin and bus conductor was left dangling one metre from the ground and clear of other structures. The bus remained alive and was discovered by personnel doing ground maintenance.

In a separate incident in 2013, after operating a three phase 22kV Powder filled fuse unit, a red phase insulator broke, dropping the conductor towards the operator. For further information, refer to ELE AM PL 0061 Primary Plant Asset Class Strategy, in Appendix A, and the two safety alerts in Appendix E – 22kV Pin and Cap insulator Failure.

This is not an issue that is driving the replacement of the indoor switchgear; however the new proposed 22kV switchgear provides an opportunity to the remove outdoor 22kV transfer buses, to remove the associated safety risk. See Appendix E for further detail: 22kV Pin and Cap Insulator Failure. If the Transfer buses were to remain in-service, the 22kV pin and cap insulators would be replaced to mitigate the known safety risk. This replacement part of the work is solely driven by a health and safety risk. There is no evidence that would indicate any supply reliability improvements as a result of the replacement of this equipment.

8. The 66kV Bus Tie Circuit Breakers represents a family of breakers with history of mechanical failure and catastrophic bushing failures. These CB's (Type LG4C) is no longer supported by the manufacturer and spare components are no longer available. This is a critical issue.

JEN presently has 9 off LG4C 66kV circuit breakers manufactured from 1964 in service, with one installed at FE. Refer to Appendix A ELE AM PL 0061 Primary Plant Asset Class Strategy.

There were two catastrophic failures of this type of CB at Brooklyn and one at West Melbourne Terminal Stations in the late 1990s and early 2000s, with these failures relating to the 66kV bushings. These CBs are no longer supported by the manufacturer and consequently spare components such as 66kV bushings, turbulators, solenoids and mechanism components are no longer available. The known failure history of 66kV bushings is a risk to the safety of JEN personnel. Continued maintenance and testing will not prevent the failure of a bushing. The cost of engineering new replacement bushings, procurement and installation would be comparable to the installation of a new CB. Additionally, replacement of the bushings alone would not address the mechanical wear and lack of spare parts.

An additional defect has been identified in the mechanism of these CBs involving the retaining of a shaft by a washer that is peened on the end of the shaft. This indicates component failure due to mechanical wear and has resulted in damage to the mechanism. A new component was designed and manufactured as original spare parts are not are not available. An inspection of all of these breakers has been undertaken and a plant defect notice issued. This shows that these CBs are entering a wear out phase. and due to a lack of spare parts, components are being reengineered independently outside of the original equipment manufacturer specification which takes time, and is costly. For example, the development of a single pin costs in excess of $5,500 to develop and the material cost was about $10. This CB mechanism defect can prevent the CB from opening or closing. In this circumstance, if a subtransmission line fault occurs, total loss of supply will be experienced at FE.

9. The Outdoor 66kV insulators are deteriorated and at risk of failure.

The outdoor 66kV insulators at FE were observed to have significant electrical discharge on most of the buses and disconnect switches. This issue causes Radio Frequency Interference (RFI) and ultimately may result in insulation failure. This is the main issue driving the replacement of the 66kV insulators, and an opportunity exists to undertake this work at the same time as the 22kV switchgear replacement at FE.

In 2012 at approximately 2330 hours, while attending to a site defect, the FE 66kV insulators were observed to be discharging throughout the switchyard due to light rain. This condition is present during rain or fog conditions causing RFI, future customer concern due to audible electrical discharge, and may lead to insulator failure. These insulators also consist of a galvanised steel pin cemented into the porcelain similar to the pin and cap 22kV insulators described above and may exhibit a similar failure mode in the future, which poses a serious safety risk to JEN personnel.

10. The DC supply system is deteriorated and at risk of failure

Most batteries at FE are beyond their design life (15 years), have deteriorated and are failing. This is the main issue driving the replacement of the DC system. This is a critical system as it is used to supply auxiliary power to protection relays, control and communication circuits, and to trip/close HV circuit breakers. If a network fault was to occur concurrently with the failure of the battery system, this would pose risks to safety, risk of damage to assets and risk of loss of supply to customers, in addition to a negative impact on Jemena's brand and reputation.

11. **Security Fence**

The external FE Zone Substation security fence requires replacement at certain sections. Parts of the existing security fence are damaged or deteriorated beyond repair, and do not provide the required security as identified in JEN’s Primary Plant Manual for a high criticality Zone Substation site.

12. **22kV Feeder Cables**

Analysis of the performance of HV paper lead cables has shown a fast-increasing trend of failure in the last three years. JEN’s investigation of the cables at Zone Substation FE has identified significant deterioration not only on the outer serving layer but on the lead sheath armour, which means the barriers from mechanical damage and moisture have been weakened, risking electrical failure. There have also been many incidents where faults occurred at the old cable head at the feeder exit cable head pole due to electrical failure caused by moisture ingress and animal contact. There are no standard animal proofing covers available for the old cable head construction and therefore animal strikes on the FE 22kV feeder exit cable head poles have occurred on average 2-3 times a year. There also have been many incidents of animal strikes on the feeder exit isolators, for which animal proofing is also not available, resulting in supply interruptions for customers.

High fault current flow will deteriorate all primary plant such as transformers and circuit breakers within Zone Substation FE, leading to increased maintenance requirements and diminishing asset life. Failure at the cable head also poses a safety risk to the public as shattered porcelain could cause death or serious injury to the public or cause damage to nearby third party property.

Given the switchgear replacement works proposed for Zone Substation FE, there is an opportunity to concurrently address issues with the HV paper lead cables and realise project management and delivery efficiencies. It is therefore proposed that the scope of this project include replacement of the whole length of 22kV feeder exit cable for existing feeders FE5, FE6, FE8 and FE9 from the circuit breaker to the cable head pole, bringing the cable head construction up to current design standards and providing full animal proofing. It is also recommended that all feeder exit HV isolators be replaced with manual gas switches where applicable.

2.1.2 CONDITION BASED RISK MANAGEMENT MODELLING RESULTS

JEN has undertaken Condition Based Risk Management (**CBRM**) modelling for switchgear assets to assist in the development of asset investment plans using existing asset data and other information. A description of the model and the results for zone substation related assets is in document ‘Jemena CBRM Report – Zone Substation Assets’, and in the Asset Class Strategies.

CBRM develops a Health Index for each asset based on a scale from 0 to 10. Values of health index in excess of seven represent serious deterioration and a need to plan for replacement before failure occurs is necessary. Refer to Appendix A - Asset Class Strategies for further details on CBRM.

The CBRM Health Index is a numeric representation of the condition of each asset. Essentially, the health index of an asset is a means of combining information that relates to its age, environment and duty, as well as specific condition and performance information to give a comparable measure of condition for individual assets in terms of proximity to end of life (**EOL**) and probability of failure. The concept is illustrated schematically below in Figure 2–10.

Figure 2–10: Switchgear Health Index (HI) scale

Condition	Health Index	Remnant Life	Probability of Failure
Bad	10	At EOL (<5 years)	High
Poor		5 - 10 years	Medium
Fair		10 - 20 years	Low
Good	0	>20 years	Very low

The CBRM modelling indicates that the FE Zone Substation No.1 and No.2 22kV buses have a current health index result of **8.41**. This indicates that the 2 buses have serious issues, including degradation and wear out failures, and due to lack of spares the probability of failure is high. These modelling results are consistent with the issues identified.

Six years from now (2025), if the switchgear is not replaced, health index result would increase to **9.65**.

For the 22kV CBs, the CBRM modelling indicates that they have a current health index result above **7.01**. This indicates that the CBs are in poor condition. This modelling result is also consistent with the issues identified. By year 6 (2025), the highest CB result becomes **8.91** if no action is taken.

For the 66kV CBs, the CBRM modelling indicates that the 1-2 bus tie CB has a current health index result of **6.88**. This indicates that the CBs are in poor condition. This modelling result is also consistent with the issues identified. By year 6 (2025), the CB result becomes **8.41** if no action is taken.

For the 66kV insulators, the CBRM modelling indicates a current health index result of **7.69**. This indicates that the insulators are in poor condition. This modelling result is also consistent with the issues identified. By year 6 (2025), the insulators result becomes **9.61** if no action is taken.

2.1.3 ASSET FAILURE RISKS

The total expected cost of equipment failure at Zone Substation FE is $2,706k per annum. This is explained by equipment type in the sub-sections below.

Due to the age and condition of the assets mentioned below, the annual cost of risk will continue to increase until the deteriorated assets are removed from service.

2.1.3.1 22kV Indoor Switchgear failure risk

Failure Modes

The failure modes of the FE 22kV switchgear can include:

- Bushing insulation failure;
- Mechanical failure (failure to open or close);
- Insulation medium degradation;
- Lightning and other line surges;

- High resistance connections;
- Failure modes resulting from Inadequate maintenance, and
- Failure modes resulting from Design/manufacturing errors.

Due the deteriorated condition of the indoor 22kV bus, insulation failure is likely occur.

Likelihood of Failure

The probability of a 22kV switchgear failure can only be estimated from limited historical data, engineering experience and condition test reports. From Table 2-3, the failure modes have been summarised below:

- Insulation degradation due to PD;
- Thermal condition, burnt contacts;
- CB trip free; and
- Leaking oil.

The thermal fault due to high resistance connections is not uncommon for oil filled CBs. Two other similar failures have occurred at JEN's zone substations FT (Flemington) and EP (East Preston), but on different switchgear. The CB thermal condition and a trip free due to mechanical wear will not be readily identifiable before any such event. The incidence of oil leaks associated with the FW switchgear is increasing and will ultimately necessitate a major maintenance work to replace gaskets.

There are 22 CBs installed at FE and FW and 71 fault records in 10 years. The major issue is the presence of PD approaching service voltage and the impact on personnel safety and the lack of spares to recover from a catastrophic failure. The insulation will continue to degrade over time due to the presence of PD. PD levels will rise and failure will ultimately occur.

Catastrophic insulation failure can be triggered by lightning and other line surges at any time. Insulation degradation at normal service voltage can be a cyclical due to temperature variations or linear increase over the same period, ultimately resulting in failure. Based on CBRM it is expected that one 22kV indoor bus could fail beyond repair due to poor condition in the next 5 years, the probability of the FE 22kV bus failing in any year is taken to be 1/5=20%. This failure rate is likely to increase with age.

Consequence of Failure

The consequence of a catastrophic failure of the 22kV switchgear at FE would likely be interruption of supply to the entire station due to smoke and potential fire. The switchgear contains bulk oil volume for insulation and to interrupt current. The scenario considered is the loss of two 22kV buses due to a bus section failure within the bus tie CB.

FE Zone Substation has ties to JEN's FW (Footscray West), BY (Braybrook) and YVE (Yarraville) Zone Substations and has approximately 25.6MVA load transfer capability under contingency condition. The forecast maximum demand at FE Zone substation is 39.4MVA for summer 2019/20 under 10POE condition.

If the feeder circuit breaker fails on either No.1 or No.2 22kV Bus this will result in the loss of the entire bus. If this happens during a maximum demand day on the No.2 22kV Bus, 35% of the station load will be lost for the duration of 1 hour until load transfers take place. In the event of a subsequent fault occurring on the No.1 66kV WMTS FDR line all the station load will be lost for an hour.

In case of a fault on the 1-2 22kV Bus Tie CB the entire station load will be lost for the duration of 1 hour initially. Depending of the type of failure that the 1-2 22kV Bus Tie CB has endured, the rectification work to reinstate the 1-2 22kV Bus Tie CB may take up to 12 weeks. During this time 13.8MVA load will be unable to be supplied. This represents approximately 3,000 residential customers which would be rotationally load shed. Restoration to system normal could take up to 12-18 months to replace all switchgear.

Network Performance

The network performance considered is for the initial failure event and not for any subsequent network faults during the 12 – 18 month replacement period.

The network performance impact (S Factor cost) is associated with this scenario would be SAIDI + SAIFI:

14,329 (Customers) x 1(hr) x 60(mins) x $0.50/min + 14,329 (Customers) x $30/Cust = $860k

CAPEX

The capital expenditure required to rectify a single permanent failure is estimated to be $11.213M. This represents the equipment replacement costs (No.1 and No.2 22kV bus) and is the same value as a planned replacement project, and is required as JEN would be unable to continue to meet the supply needs of customers in the FE area without this equipment being rectified. This capital expenditure is based on estimates prepared by Project Managers.

OPEX

The operating expenditure associated with a single permanent failure is estimated to be less than $120k. This represents the costs associated with the forced outage resulting from the bus failure including activities such as network operations to restore supply, repairs to other equipment and any safety related costs.

Total Cost of Risk

The expected cost of risk for a bus failure has been determined using the results outlined above. This represents the *annual* risk.

Cost of Risk p.a. **= ($ Network Performance + $ CAPEX + $ OPEX) x Probability**
= ($860k + $11,213k + $120k) x 20%
= $2,439k p.a.

Due to the age and condition of the assets mentioned above, the above cost of risk will continue to increase until the assets are removed from service

2.1.3.2 66kV CB failure risk

Failure Modes

The failure modes of a circuit breaker can include:

- Bushing insulation failure;
- Mechanical failure (failure to open or close);
- Insulation medium degradation;
- Lightning and other line surges;

- High resistance connections;
- Failure modes resulting from Inadequate maintenance; and
- Failure modes resulting from Design/manufacturing errors.

A CB can fail due to thermal, electrical or mechanical factors however whilst a typical failure mode is difficult to determine, most failures involve a failure to operate.

Likelihood of Failure

The probability of a 66kV CB failure at FE can only be estimated from knowledge of other failures of CB from that family. There were two catastrophic failures of this type of CB at Brooklyn and one at West Melbourne Terminal Stations in the late 1990s and early 2000s and these failures related to bushings.

There have been numerous other failures of this type of CB and these include:

- 1984 – AW – Failed to close;
- 1982 – ERTS – Damaged during electrical storm;
- 1986 – TTS – Damaged during electrical storm;
- 1986 – HTS – Failure to trip;
- 1994 – CW – Failed to trip;
- 2000 – AW – Failed to trip;
- 2001 – CS – Failed to trip; and
- 2010 – HB – Failed to operate

The likelihood of a mechanical failure is low as these 66kV CBs are not called on to operate due to faults very often. Failures can be pickup during maintenance. Refer to section 2.1.1 - Asset Condition.

The ten failure observations mentioned above have occurred in the past thirty years giving a probability of failure of 1 in 3 years. Given that the 16 of this type of CB in service on the JEN, the probability of the FE 66kV CB failing in any year is estimated to be 1/3/16=2%.

In consideration of a catastrophic bushing failure of 3 in 15 years and a population of 16 CBs, the probability of the FE 66kV CB failure scenario eventuating in any year is taken to be 1.25% (3/15/16).

Consequence of Failure

The consequence of a catastrophic failure of the 66kV CB at FE would likely be interruption of supply to the entire station. It is likely that the station could be off supply for up to 1 hour whilst damage was assessed, any necessary minor repairs undertaken and supply restored. The amount of clean up would be minimal given the low oil volumes involved. Any further similar event will result in significant customer outages.

The CB would need to be replaced and the 2 transformers at FE would be a single 66kV line contingency for approximately 4 months whilst the replacement was procured and installed.

Network Performance

The network performance impact (S Factor cost) is associated with this scenario would be SAIDI + SAIFI:

14,329 (Customers) x 1(hr) x 60(mins) x \$0.50/min + 14,329 (Customers) x \$30/Cust = \$860k

CAPEX

The capital expenditure associated with a single permanent failure is estimated to be \$350k. This represents the equipment replacement costs and is the same value as a planned replacement project.

OPEX

The operating expenditure associated with a single permanent failure would not be significant and is estimated to be less than \$10k. This represents the costs associated with the forced outage resulting from the CB failure including activities such as network operations to restore supply, minor repairs to other equipment and any safety related costs.

Total Cost of Risk

The expected cost of risk for a CB failure has been determined using the results outlined above. This represents the annual potential impact.

Cost of Risk p.a. = (\$ Network Performance + \$ CAPEX + \$ OPEX) x Probability
= (\$860k + \$350k + \$10k) x 1.25%
= \$15.3k p.a.

Due to the age and condition of the assets mentioned above, the above cost of risk will continue to increase until the assets are removed from service

2.1.3.3 Outdoor 22kV Transfer Bus failure risk

Failure Modes

The failure modes of a 22kV bus can include:

- Insulator electrical failure;
- Mechanical failure;
- Lightning and other line surges;
- High resistance connections;
- Failure modes resulting from Inadequate maintenance; and
- Failure modes resulting from Design/manufacturing errors.

A bus can fail due to thermal, electrical or mechanical factors however whilst a typical failure mode is difficult to determine, the likely failure would be due to insulator flashover or mechanical damage.

Likelihood of Failure

The probability of an outdoor 22kV bus section at FE is low. For risk/cost calculations, a 1% probability of failure in any particular year is used.

Consequence of Failure

The consequence of a failure of an outdoor 22kV transfer bus section at FE would likely be interruption of supply to one feeder and these customers would be off supply until repairs were completed.

The failure however would have serious consequences if it occurred during switching operations and was the result of an operator opening or closing the 22kV underslung isolators on a feeder. Falling porcelain/equipment and/or contact with live 22kV conductors could cause permanent disability or even death to a staff member.

Network Performance

The network performance impact (S Factor cost) is associated with this scenario would be SAIDI + SAIFI:

3,000 (Customers) x 1(hrs) x 60(mins) x $0.50/min + 3,000 (Customers) x $30/Cust = $180k.

CAPEX

The capital expenditure associated with a single permanent failure is estimated to be $4k. This represents the equipment replacement costs for one 22kV underslung isolator. There are 16 outdoor underslung isolators in question and estimated total cost to replace is $64k.

OPEX

The operating expenditure associated with a single permanent failure would not be significant and is estimated to be less than $5k. This represents the costs associated with the forced outage resulting from an insulator failure including activities such as network operations to restore supply, minor repairs to other equipment and any safety related costs.

Total Cost of Risk

The expected cost of risk for a CB failure has been determined using the results outlined above. This represents the annual potential impact.

Cost of Risk p.a. **= ($ Network Performance + $ CAPEX + $ OPEX) x Probability**
= ($180k + $64k + $5k) x 1%
= $2.5k p.a.

Due to the age and condition of the assets mentioned above, the above cost of risk will continue to increase until the assets are removed from service

2.1.3.4 Outdoor 66kV bus failure risk

Failure Modes

The failure modes of a 66kV bus can include:

- Insulator electrical failure;
- Mechanical failure;
- Lightning and other line surges;
- High resistance connections;
- Failure modes resulting from Inadequate maintenance; and
- Failure modes resulting from Design/manufacturing errors.

A bus can fail due to thermal, electrical or mechanical factors however whilst a typical failure mode is difficult to determine, the likely failure would be due to insulator flashover or mechanical damage.

Likelihood of Failure

The probability of an outdoor 66kV bus section at FE is low. For risk/cost calculations, a 1% probability is used.

Consequence of Failure

The consequence of a failure of an outdoor 66kV bus section at FE would likely be interruption of supply to one transformer with no interruption to customer supply. Only a single event is considered.

The failure however would have serious consequences if it occurred during switching operations and was the result of an operator opening or closing the 66kV underslung isolators on a feeder. Falling porcelain/equipment and/or contact with live 66kV conductors could cause permanent disability or even death to a staff member.

Network Performance

The network performance impact (S Factor cost) would not be impacted for a single event.

CAPEX

The capital expenditure associated with a single permanent failure is estimated to be $4k. This represents the equipment replacement costs for one phase of a 66kV isolator. The total cost to replace all of the 66kV insulators as a project is estimated to be $440k. See section 4.1 for the project cost estimate.

OPEX

The operating expenditure associated with a single permanent failure would not be significant and is estimated to be less than $5k. This represents the costs associated with the forced outage resulting from an insulator failure including activities such as network operations to restore supply and minor repairs to other equipment.

Total Cost of Risk

The expected cost of risk for a CB failure has been determined using the results outlined above. This represents the annual potential impact.

Cost of Risk p.a. **= ($ Network Performance + $ CAPEX + $ OPEX) x Probability**
= ($0 + $440k + $5k) x 1%
= $4.5k p.a.

Due to the age and condition of the assets mentioned above, the above cost of risk will continue to increase until the assets are removed from service.

2.1.3.5 DC system

Failure Modes

The failure modes of a DC system can include:

- Failure of a battery bank;
- Loss of integrity of battery and acid spill;

- Failure modes resulting from Design/manufacturing errors.

Most common failure involves a failure of the DC system to supply power.

Likelihood of Failure

Given that condition of most batteries has deteriorated and frequent top up of water is required, the probability of failure is considered to be 20%.

Consequence of Failure

The consequence of a catastrophic failure of a battery bank is loss of auxiliary supply to critical protection, control and communication equipment which may require load transfer to other Zone Substations. It is likely that the station could be off supply for minimum of 1 hour whilst damage was assessed, any necessary minor repairs undertaken and supply restored.

Network Performance

The network performance impact (S Factor cost) is associated with this scenario would be SAIDI + SAIFI:

14,329 (Customers) x 1(hr) x 60(mins) x $0.50/min + 14,329 (Customers) x $30/Cust = $860k

CAPEX

The capital expenditure associated with a single permanent failure is estimated to be $75k. This represents the equipment replacement costs and is the same value as a planned replacement project.

OPEX

The operating expenditure associated with a single battery bank permanent failure is estimated to be less than $5k. This represents the costs associated with having an operator at site and managing the load transfers including activities such as network operations to restore supply and any safety related costs.

Total Cost of Risk

The expected cost of risk for a DC system failure has been determined using the results outlined above. This represents the annual potential impact.

Cost of Risk p.a. = ($ Network Performance + $ CAPEX + $ OPEX) x Probability
= ($860k + $75k + $5k) x 20%
= $188k p.a.

Due to the age and condition of the assets mentioned above, the above cost of risk will continue to increase until the assets are removed from service.

2.1.3.6 Security Fence

Failure Modes

Structural failure of the security fence, as sections of the fence has reached end of life due to timber rot.

Likelihood of Failure

The probability of the fence failure to maintain a secure site is low. For risk/cost calculations, a 20% probability is used as regular inspection and repair work is undertaken.

Consequence of Failure

The consequence of a failure of the security fence at FE would likely be interruption of customer supply as the outdoor circuit breakers can be operated manually and DRMCC can trip the transformers.

The failure of the fence to maintain a secure site can also have serious consequences for any intruder if equipment inside the Zone Substation was to fail catastrophically or safe approach distances were compromised. This could result in death or serious injury to an intruder.

Network Performance

The network performance impact (S Factor cost) is associated with this scenario would be SAIDI + SAIFI:

14,329 (Customers) x 2(hr) x 60(mins) x $0.50/min + 14,329 (Customers) x $30/Cust = $1,290k

CAPEX

The capital expenditure associated with a single permanent failure is estimated to be $100k. This represents the equipment replacement costs and is the same value as a planned replacement project.

OPEX

The operating expenditure associated with a single failure would not be significant and is estimated to be less than $10k. This represents the costs associated with the CB failure including activities such as network operations to restore supply, minor repairs to other equipment and any safety related costs.

Total Cost of Risk

Cost of Risk p.a. = ($ Network Performance + $ CAPEX + $ OPEX) x Probability
= ($1,290k + $100k + $10k) x 1.00%
= $15.3k p.a.

2.1.3.7 Feeder cables

Failure Mode

Due to the poor condition of the feeder cables installed in 1967, cable pot heads or joints are likely to fail due to degraded insulation and corroded steel armouring.

Likelihood of Failure

The probability of a 22kV feeder cable failure is 23% which will be used for risk/cost calculations.

Consequence of Failure

The consequence of failure of a single 22kV feeder cable at FE would likely be interruption of supply to 3,000 customers.

<u>Network Performance</u>

The network performance impact (S Factor cost) is associated with this scenario would be SAIDI + SAIFI:

3,000 (Customers) x 1(hrs) x 60(mins) x $0.50/min + 3,000 (Customers) x $30/Cust = $180k.

<u>CAPEX</u>

The capital expenditure associated with a single permanent failure of one 22kV feeder cable is estimated to be $25k. This represents the equipment rectification costs.

<u>OPEX</u>

The operating expenditure associated with a single failure would not be significant and is estimated to be less than $10k. This represents the costs associated with the identifying the location of the cable fault including activities such as network operations to restore supply, minor repairs to other equipment and any safety related costs.

<u>Total Cost of Risk</u>

Cost of Risk p.a. = ($ Network Performance + $ CAPEX + $ OPEX) x Probability
= ($180k + $25k + $10k) x 23.00%
= $41.5k p.a.

2.2 PROJECT OBJECTIVES AND ASSESSMENT CRITERIA

2.2.1 OBJECTIVE

The objective of the project is to maintain reliability of supply to customers at FE given the current condition of FE assets. This strategy must be consistent with other JEN Strategy and plans and the project must comply with associated regulatory requirements.

2.2.2 REGULATORY REQUIREMENTS

JEN's investment decisions are ultimately guided by the National Electricity Objective. Additionally, considerations such as the capital expenditure objectives set out in the National Electricity Rules are particularly relevant to JEN's investment decisions. The capital expenditure objectives are set out in section 6.5.7 of the National Electricity Rules:

a) *A building block proposal must include the total forecast capital expenditure for the relevant regulatory control period which the Distribution Network Service Provider considers is required in order to achieve each of the following (the capital expenditure objectives):*

(1) *meet or manage the expected demand for standard control services over that period;*

(2) *comply with all applicable regulatory obligations or requirements associated with the provision of standard control services;*

(3) *to the extent that there is no applicable regulatory obligation or requirement in relation to:*

> *(i) the quality, reliability or security of supply of standard control services; or*
>
> *(ii) the reliability or security of the distribution system through the supply of standard control services,*
>
> *to the relevant extent:*
>
> *(iii) maintain the quality, reliability and security of supply of standard control services; and*
>
> *(iv) maintain the reliability and security of the distribution system through the supply of standard control services; and*
>
> *(4) maintain the safety of the distribution system through the supply of standard control services.*

Additionally, the Victorian Electricity Distribution Code sets out provisions relevant to JEN's planning, design, maintenance and operation of its network, most relevantly section 3.1 (Good Asset Management):

> *A distributor must use best endeavours to:*
>
> *a) assess and record the nature, location, condition and performance of its distribution system assets;*
>
> *b) develop and implement plans for the acquisition, creation, maintenance, operation, refurbishment, repair and disposal of its distribution system assets and plans for the establishment and augmentation of transmission connections:*
>
> - *to comply with the laws and other performance obligations which apply to the provision of distribution services including those contained in this Code;*
> - *to minimise the risks associated with the failure or reduced performance of assets; and*
> - *in a way which minimises costs to customers taking into account distribution losses; and*
>
> *c) develop, test or simulate and implement contingency plans (including where relevant plans to strengthen the security of supply) to deal with events which have a low probability of occurring, but are realistic and would have a substantial impact on customers.*

Section 5.2 (Reliability of Supply) of the Electricity Distribution Code also states:

> *A distributor must use best endeavours to meet targets required by the Price Determination and targets published under clause 5.1 and otherwise meet reasonable customer expectations of reliability of supply.*

In respect to the nominated assets, Jemena seeks to comply with these regulatory obligations through the development and implementation of its Primary Plant Asset Class Strategy. The Zone Substation Primary Plant Asset Class Strategy is also listed in Appendix A.

2.2.3 ASSESSMENT CRITERIA

The assessment criteria by which projects will be assessed against and the extent to which each of the identified options address the Twelve asset condition issues are described in Section 1.1. Valid options that address the

Twelve critical issues are described in Section 3.1 and are analysed from both a net present value and network risk perspective to determine the preferred option.

2.3 CONSISTENCY WITH JEMENA STRATEGY AND PLANS

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

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

JEN seeks to ensure that whole of lifecycle costs are minimised. This business case has considered and is consistent with this requirement, including that the selected option is consistent with the long term vision for the network as set out in the AMP and annual planning reports.

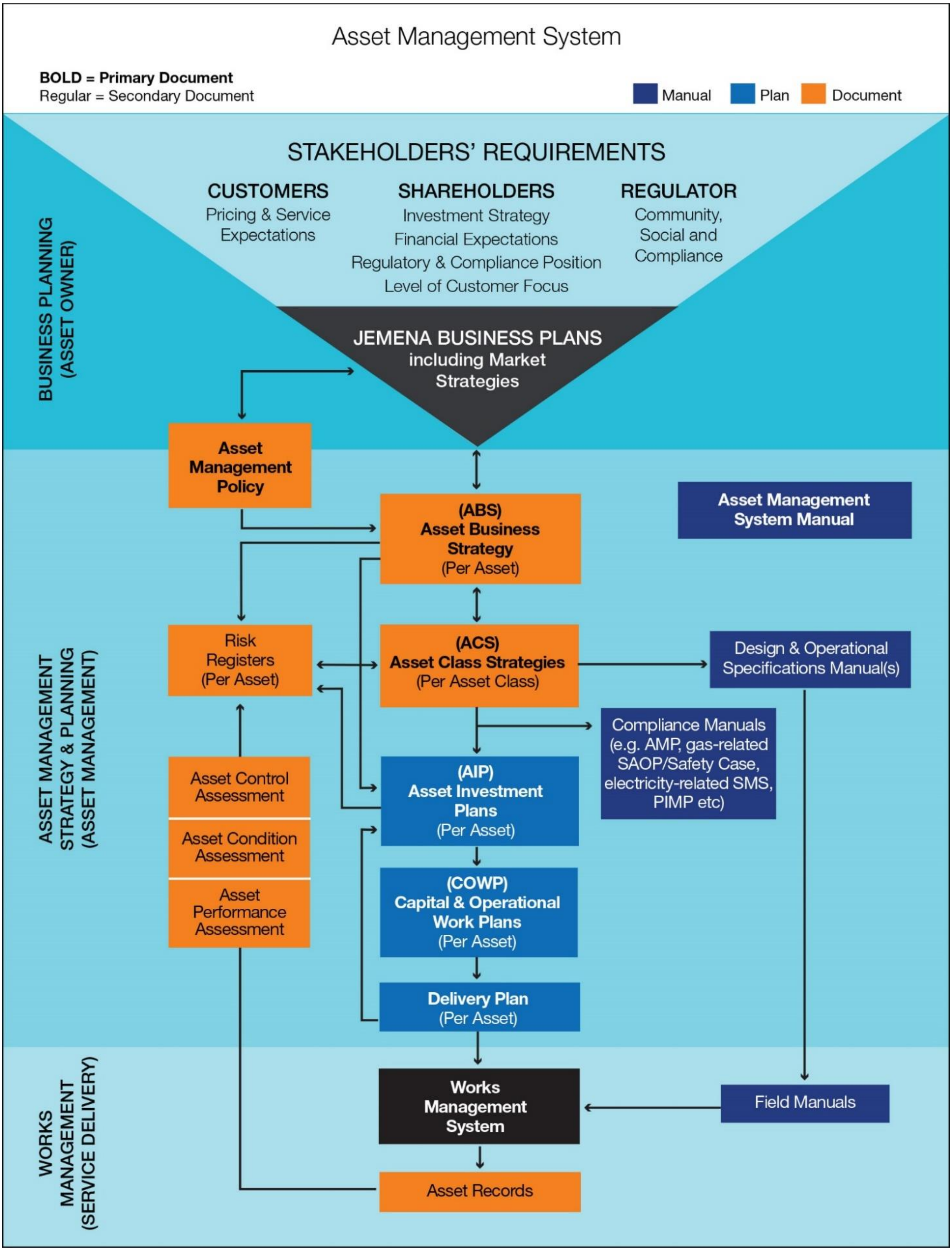
JEN must comply with regulatory obligations; these are incorporated into the development and implementation of its Electricity Primary Plant Asset Class Strategy. The Asset Class Strategy creates a line of sight between the JEN Business Plan and the Asset Management Plan.

This proposal aligns with Asset Management Strategies, Plans & Policies as it will contribute to ensuring a safe place of work for JEN employees and contractors. By addressing the issues identified, JEN can reduce the risk of injury to its staff or members of the public, and reduce its exposure to the possibility of litigation by authorities due to an injury or environmental incident.

Figure 2–11 outlines the Jemena asset management system and where the Asset Management Plan (AMP) is positioned within it. The AMP covers the creation, maintenance and disposal of assets including investment planned to augment network capacity to meet increasing demand and to replace degraded assets to maintain reliability of supply to meet Jemena Business Plan requirements.

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

Figure 2–11: The Jemena Asset Management System



3. CREDIBLE OPTIONS

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

3.1 IDENTIFYING CREDIBLE OPTIONS

The following feasible options could be used to address the business need, problem or opportunity.

- Do Nothing
- Increased Maintenance and Monitoring
- 22kV and 66kV Switchgear Refurbishment
- Transfer Load
- Replace Switchgear.

The extent to which each of the identified options addresses the issues is shown in Table 3-1.

3.2 DEVELOPING CREDIBLE OPTIONS COSTS & BENEFITS

The credible options are discussed in the following sub-sections. Note that all expected option costs include overheads. The extent to which each of the identified options addresses the issues is shown in the table below.

Table 3-1: Switchgear Options Analysis

Condition Issue	Option 1 Do Nothing	Option 2 Increased Maintenance and Monitoring	Option 3 Refurbishment	Option 4 Load Transfer (Build a new Zone Substation)	Option 5 Replacement
Issue 1 Switchgear Condition	○	○	○	●	●
Issue 2 Non ARC fault Containment	○	○	○	●	●
Issue 3 Lack of Spare Parts	○	○	○	●	●
Issue 4 Insulation Oil Leaks	○	◐	●	●	●

Condition Issue	Option 1 Do Nothing	Option 2 Increased Maintenance and Monitoring	Option 3 Refurbishment	Option 4 Load Transfer (Build a new Zone Substation)	Option 5 Replacement
Issue 5 Nonstandard Test procedures	○	○	○	●	●
Issue 6 Maintenance Intensive	○	○	◑	●	●
Issue 7 22kV Insulators	○	○	○	●	●
Issue 8 66kV CB's	○	○	◑	●	●
Issue 9 66kV Insulators	○	○	○	●	●
Issue 10 DC Supply	○	○	○	●	●
Issue 11 Security Fence	○	○	○	●	●
Issue 12 Feeder Cables	○	○	○	●	●
Technically Viable	○	○	○	◑	●

●	Fully addressed the issue
◕	Adequately addressed the issue
◑	Partially addressed the issue
○	Did not address the issue

Each of these options are discussed below.

3.3 OPTIONS ANALYSIS

Each of the options, identified in Section 3.1, are discussed below.

3.3.1 OPTION 1 - DO NOTHING

The do nothing option assumes a business as usual scenario. The current maintenance activities associated with the 22kV switchgear would continue including inspections, condition monitoring, preventive work and repair of defects. Maintenance will not improve the insulation condition and PD cannot be prevented when the defect is embedded within the insulation. In this case, maintenance is inadequate to maintain reliability. Increased condition monitoring tasks will be needed to identify when safety restriction limiting access to the switchgear would need to be put in place. These tests would continue until the switchboard is at imminent risk of catastrophic failure and it would then be taken out of service, thus placing the supply reliability at increased risk for 6 to 18 months while a replacement solution is designed and manufactured.

This option would allow management of the oil leaks issue (Issue 4) but would be unlikely to solve it. The option does not permanently address any of the other condition issues described in Section 2.1. In particular, the 22kV switchgear condition (Issue 1) would not be resolved and the probability of failure of at least two of the buses would remain. In event of a bus failure, it is anticipated that load transfer or load shedding would be required.

The 22kV switchgear insulation is in poor condition and the degradation that has occurred is irreversible. For this reason, option 1 is considered to be not credible as the point of failure of this equipment cannot be predicted even with condition testing, risking the catastrophic failure of the switchboard in service, resulting in potentially significant supply interruptions for customers in the FE supply area and a serious safety risk to JEN personnel. Given the criticality of this issue, it is not recommended to pursue any option that does not address it.

3.3.2 OPTION 2 - INCREASED MAINTENANCE & MONITORING

Under this option, the FE switchgear would be more closely monitored and the frequency and range of condition testing would be increased. The ultimate failure of the bus cannot be prevented if the switchgear remains in-service, regardless of the maintenance and monitoring program. Condition of the insulation will continue to deteriorate until ultimate failure occurs impacting on reliability and safety. For this reason, option 2 is not considered.

This option does not address any of the issues described in Section 2.1. In particular, the asset condition of the 22kV and 66kV switchgear, including the outdoor 22kV isolators would not be resolved and the risk of failure and impact on personnel safety of these assets would remain. This is therefore not a credible option.

Maintenance of the 22kV internal oil immersed isolators may need to be introduced, however this option does not address any of the six issues described in Section 2.1. In particular, the insulation condition (Issue 1) would not be resolved and the probability of failure of the switchgear would remain. Given the criticality of this issue, it is not recommended to pursue any option that does not address Issue 1.

3.3.3 OPTION 3 - SWITCHGEAR REFURBISHMENT

The 22kV switchgear refurbishment is not credible as the replacement of individual busbar or bushings is no longer supported by the manufacturer, and any such action if possible would be cost prohibitive. This option would therefore only address oil leaks, and the switchgear performance, safety and reliability would not change from the original design in 1937 which does not conform to current Australian Standards AS 62271 for arc fault containment.

66kV bushing replacement (if replacements are available) for the LG4C CB only partially addresses the issues associated with this CB. Spare parts for this CB are not available, and additionally this model’s bulk oil design presents a fire risk and is maintenance intensive. It is for these reasons that this option is not considered as a credible option.

3.3.4 OPTION 4 - TRANSFER LOAD (BUILD A NEW ZONE SUBSTATION)

The transfer load option involves the transfer of all load away from FE and the temporary or permanent retirement of the FE zone substation. If all load was transferred away from FE then the substation could either be demolished and the land sold or simply mothballed until an appropriate time when the substation could be rebuilt and re-commissioned.

Decommissioning of the deteriorated equipment at FE would mitigate all of the current condition issues identified in section 2.1.

Although approximately 65% of the load can be transferred to adjacent feeders without any capital investment, this would place restrictions on any further network operations. There would be no further contingencies available, as JEN would be unable to transfer load to adjacent feeders during network faults, resulting in extended supply outages for customers. This would have a direct impact on JEN's STPIS performance in terms of SAIDI and SAIFI. Additionally, a number of similar switchgear condition issues exist at the nearby FW Zone Substation, which may further restrict load transfer opportunities.

In the event of the FE switchgear failing, which represents half of the station's load, load transfers will need to be in place for approximately 8 months while a new switchboard is procured, installed and commissioned. Any further significant event may result in rotational load shedding, which would have a significant impact on customers.

The forecast maximum demand for summer 2019/20 at FE is 39.4MW. If a new zone substation were to be constructed, it would require two 33MVA transformers, 22kV switchgear, new feeders, and an extended control building with all associated protection and control equipment for a new zone substation.

Establishment of a green field zone substation is estimated to be in excess of $25M. This estimate is conservative due to the likely additional costs associated with establishing sub-transmission circuits and acquiring land in well-established urban areas, however the figure will be used as a basis for comparison.

In general, it is not economically viable establishing a new Zone Substation to replace FE is unlikely to be considered a prudent method of addressing the condition of the existing assets at FE.

It is for these reasons that this option is not considered.

3.3.5 OPTION 5 - REPLACE SWITCHGEAR

This option involves replacing the existing 22kV and 66kV switchgear with new modern equivalents and installing them to current standards, including the retirement of the outdoor 22kV transfer buses, DC system and new security fence. The new indoor metalclad switchgear would conform to current safety standards including arc fault containment. This would address all the condition issues identified in Section 2.1 and will allow JEN to maintain the safety, reliability and security of customer supply in the FE area.

The total cost of this option is estimated to be $5,803K (total project cost, real $2019) and the project would commence in 2020. The switchgear will then be over 82 years old.

4. OPTION EVALUATION

This section discusses the economic analysis used to identify the most efficient investment option – the preferred option.

4.1 ECONOMIC ANALYSIS

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

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

4.1.1 SUMMARY OF CREDIBLE OPTIONS' EXPECTED COSTS & MARKET BENEFITS

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

Table 4-1: Economic Analysis Results Summary

Description ($'000s, $2019)	Option 1 Do Nothing	Option 4 Transfer Load	Option 5 Replace Switchgear
Total Expected costs	0	25,000	5,803
Total Expected market benefits	0	33,518	33,518
Net market benefits	0	8,518	27,715
Option ranking	3	2	1

5. PROJECT TIMING

The major issue is the presence of PD at near service voltage and the impact on personnel safety and the lack of spares to recover from a catastrophic failure. The insulation will continue to degrade over time due to the presence of PD. PD levels will consequently rise and failure will ultimately occur. Refer to section 2.1.1 - Asset Condition. The switchboard has been subjected to Condition Monitoring tests in 2008 and 2018. The test results from the 2018 Condition Monitoring are showing further degradation of insulation since the 2008 tests in all of the tests conducted (Partial Discharge, Dielectric Dissipation Factor & Capacitance and Insulation Resistance).

Catastrophic insulation failure can be triggered by lightning and other line surges anytime over the next 5 years. Insulation degradation at normal service voltage can be a cyclical due to temperature variations or linear increase over the same period, ultimately resulting in failure. Based on CBRM it is expected that one 22kV indoor bus could fail beyond repair due to poor condition in the next 5 years. The probability of the FE 22kV bus failing in any given year is taken to be 1/5=20%. This failure rate is likely to increase with age as the equipment's condition deteriorates further.

Consequently, this project is scheduled to commence in 2020 and be completed by 2021.

6. REGULATORY TREATMENT

The rationale for this project is to maintain, rather than improve network performance and address safety risks through the timely replacement of aged plant that is in poor condition. Maintaining network performance will be achieved by avoiding the impact of a failure of one or more of the 22kV Buses at FE.

Maintaining network performance is consistent with the objectives of the Asset Class Strategy for Zone Substation circuit breakers to:

- Achieve at least a 50 year service life, and
- Minimise supply interruptions to customers.

Refer to Appendix A for the Asset Class Strategy

If the FE switchgear remains in service and the identified issues are not addressed, its condition will continue to deteriorate with growing risks to employee safety, and the reliability of customer supplies will decrease.

The recommended option is to replace the switchgear as it is consistent with regulatory requirements in section 6.5.7 of the National Electricity Rules (specifically, allowing JEN to maintain the quality, reliability and security of supply of standard control services, and maintain the reliability and security of the distribution system through the supply of standard control services), and section 3.1 of the Electricity Distribution Code.

Since this project satisfied the RIT-D threshold, JEN published a RIT-D Stage 1: Non-network Options Screening Report for this project on 1 February 2019[5]. As part of the report, JEN assessed potential network and non-network options to address the identified need. The analysis demonstrated that there are no combinations of non-network options, or non-network and network options, that are likely to adequately meet the criteria that would necessitate the production of a non-network options report. JEN has not received any submission on its non-network options screening report until the date of writing this business case.

As the preferred network option is less than $11 million, JEN did not intend to publish a draft project assessment report per clause 5.17.4(n) of the NER. Furthermore, as the preferred option is less than $20 million, Jemena will conclude its RIT-D process by publishing its final project assessment report summary as part of its Distribution Annual Planning Report (**DAPR**) 2019.

[5] https://jemena.com.au/documents/electricity/fe-switchgear-condition_rit-d_non-network-options.aspx

7. RECOMMENDATION

It is recommended that Option 5 be adopted and the two 22kV metalclad buses, the 66kV bus tie and line CBs, 66kV insulators, DC supply system and security fences be replaced with new modern equivalents installed to current standards, together with associated protection and control schemes. The new 22kV switchboard will be fully rated, arc fault contained, utilising vacuum circuit breakers.

This option is considered prudent as it maximises the net present value to JEN's customers and addresses all identified issues, therefore mitigating negative impacts on safety, reliability and security of customer supply.

The total cost of this option is estimated to be $5,803K (total project cost, real $2019) and the project would commence in 2020.

Appendix A
Asset Class Strategies

A1. ASSET CLASS STRATEGIES

Refer to the following document link:

ELE AM PL 0061 Primary Plant Asset Class Strategy

Appendix B
Incident Investigation FDR FW13 CB

B1. INCIDENT INVESTIGATION FDR FW13 CB

JEMENA ELECTRICITY NETWORKS

ASSET INCIDENT INVESTIGATION

FEEDER FW13 22KV CB CONTACT FAILURE AT ZONE SUBSTATION FW (FOOTSCRAY WEST)

Executive Summary

On Friday 30 August 2013, after a fault on feeder FW13 an operator attended zone substation FW (Footscray West) and found FDR FW13 22kV CB to be significantly warmer than usual. The control room was notified and the CB was removed from service.

On 11/9/2013 field personnel investigated the CB and revealed that the white phase fixed contact had melted due to a high resistance connection and was about to fail. New contacts were installed on all 3 phases and the CB was returned to service on 15/9/2013. No customers were interrupted as a result of the outage.

Incident Details

On Thursday 29 August 2013, feeder FW13 sustained a phase to ground fault at 00:10 and successfully reclosed. The fault occurred 1.1km from the zone substation and had a magnitude of 7000A. The line was patrolled by a network operator at 8:59 with no evidence found of the cause.

On Friday 30 August 2013, an operator attended zone substation FW and whilst replacing CB status indicating globes noticed that FDR FW13 22kV CB surface was unusually warm. The control room was contacted who forwarded the information onto the Primary Plant group. Due to the location of the heat, Primary Plant concluded that the most likely cause was a high resistance connection within the CB interruption chamber. The control room were instructed by Primary Plant to remove the CB from service immediately.

On Wednesday 11 September 2013, the fitters removed the bolts from the 3 individually hinged doors on the lower section of FDR FW13 22kV CB to investigate. Upon removal it was found that the white phase fixed contact had suffered significant damage and could have failed catastrophically at any time if the CB had remained in service. Due to the melting and break down of the white phase fixed contact, it was difficult to determine the cause of the failure. It is envisaged that a high resistance connection, most likely the failure of a spring mounted behind a cluster finger, has caused an individual finger within the contact cluster to lose compression and ultimately cause thermal run away.

On Friday 13 September 2013, new fixed and moving contacts were installed on all 3 phases and FDR FW13 22kV CB was returned to service.

Impact

There was no impact to JEN network because feeder FW13 was paralleled in the distribution network before FDR FW13 22kV CB was taken out of service and investigated.

Site Observations

Photos before rectification works:

Picture 1: The 22kV white phase fixed contact suffered significant damage. Due to the extent of the damage it is difficult to ascertain the cause but it is anticipated that a small spring that sits behind a contact finger has lost compression and created a high resistance connection.

Picture 2: The white phase fixed contact cluster is removed from the shaft. The heat generated from the contact failure caused 2 threads to melt away. Local judgement ascertained that the current carrying capability is not through the thread but primarily through the base of the contact as indicated by the arrow. Therefore the old thread was retained and new contacts were installed.

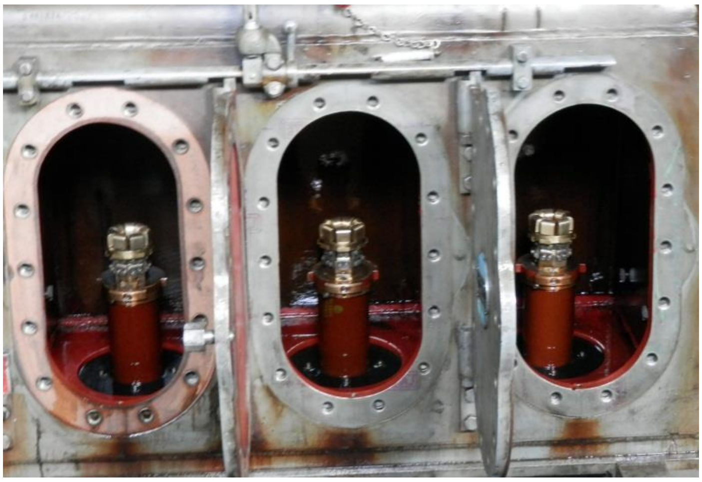
Picture 3: The failed white phase contact and associated turbulator are on the left of the picture.

The red phase healthy contact and associated turbulators are on the right side of the picture for

Photos post rectification works:

Picture 4: New fixed contact installed on white phase of FDR FW13 22kV CB

Picture 5: FDR FW13 22kV CB white phase moving contact



Picture 6: New fixed and moving contacts were installed on all 3 phases of FDR FW13 22kV CB. The new fixed contacts can be seen in picture.

Action Taken to Repair

FDR FW13 22kV CB was removed from service on 30/8/2013 and inspected for damage on the 11/9/2013. It was discovered that the white phase 22kV fixed contact had suffered significant damage. After the white phase contact cluster was unscrewed, it was also discovered that the heat generated by the failure melted away 2 threads from the bushing stem. Before the failure the 2 threads in question sat above the contact cluster when screwed on tightly and therefore did nothing from a mechanical perspective. Electrically the current primarily travels through the bottom of the cluster as indicated by the red arrows in picture 2. It was concluded that the loss of the 2 threads would not affect the electrical or mechanical integrity of the CB.

During the outage all 3 fixed and moving contacts were replaced on all 3 phases.

FDR FW13 22kV CB was returned to service on the 15/9/2013. Considering field crews limited exposure to this switchgear type, the switchgear age (76 years old) and lack of spares it was an excellent outcome.

Investigation and Analysis

Investigation Team Members

- Simon Anderson: Primary Plant and Distribution Systems Engineer
- Les Foremen: Electrical Tech/Fitter Team Leader
- Troy Schembri: Electrical Network Operator

Investigation Structure

NAPs are investigating this incident. Works delivery, namely the electrical fitters, completed the required maintenance works.

Fault History

The Metropolitan-Vickers type switchgear at zone substation FW was manufactured to a 1937 specification. FDR FW13 22kV CB was last maintained on 17/09/2009, where all test results taken post maintenance were satisfactory. Notably the condition of the contacts before maintenance was ‘Good’ and ductor test results post maintenance were all satisfactory (<121μΩ). Therefore the contact deterioration has occurred between 17/08/2009 and 30/8/2013.

Post 17/3/2009 10 faults occurred on FDR FW13 22kV CB accumulating a total of 57 points. When a CB has deteriorated as a result of fault current interruptions to the point where it requires maintenance before being returned to service, it is deemed to have acquired 100 points. FDR FW13 22kV CB is fitted with one-shot (two trips) auto-reclose and therefore must be maintained at 100 points minus the points for 2 bus faults. A 3 phase bus fault on FDR FW13 22kV CB accumulates 18 points. Consequently FDR FW13 22kV CB is due for maintenance at 64 points. Therefore leading up to the fault using the points system FDR FW13 22kV CB required 7 points before a maintenance interval requirement.

Root Cause of Failure and Contributing Factors

The 22kV switchgear at FW is 76 years old and poses a higher risk of fatigue and rate of deterioration of components such as springs which can lead to poor contact pressures between the fixed and moving contacts. Poor contact pressures and connection can result in overheating caused by the high resistance which eventually causes thermal run-away. It is anticipated that this incident was caused by poor connection of these contacts in the circuit breaker.

Conclusions, Recommendations, Actions and Timeline

FDR FW13 22kV CB had new fixed and moving contacts installed on all 3 phases. It is recommended that annual thermal scans are continually completed and used to closely monitor the condition of FW 22kV switchgear until its replacement in 2017/18. Due to the age of the 22kV switchgear at FW and this most recent failure, during the next scheduled maintenance it is recommended that particular attention is given to the fixed and moving contacts and turbulators as follows:

- Verification of contact penetration to specification for each fixed and moving contact;
- Verification of contact profile to specification for each fixed and moving contact finger;
- Verification of sufficient contact pressure by backing springs in contact cluster;
- Verification of contact alignment;
- Verify that all contacts and bolts have been checked for tightness;
- Ensure contact resistance is within the acceptable range. Suspect or loose fixed and moving contacts should be replaced;
- Visual inspection of the turbulators condition and replacement as required;
- If a defect is found, an engineer is to be contacted and on site before the circuit breaker is dismantled;
- Care must be taken to ensure no parts of plant equipment are missing when performing maintenance, and;
- Good maintenance practices must be applied to all plant maintenance.

Action No.	Action Description	Department Owner	Action Owner(s)	Target Date
1)	Install new fixed and moving contacts on all 3 phases of FDR FW13 22kV CB.	Works Delivery	Les Foreman	Complete
2)	Attach this investigation report to all applicable SAP Maintenance Plans.	Network Planning & Engineering	Simon Anderson	30/11/2013

Appendix C
Test Report for FE and FW

C1. TEST REPORT FOR FE AND FW

AusNet Transmission Group Pty Ltd
Select Solutions
308 Hyde Street,
Yarraville, Victoria 3013

A.C.N. 079 798 173
A.B.N. 78 079 798 173
Telephone: (03) 9688 1400
Facsimile : (03) 9688 1414

TEST REPORT

Condition Monitoring on No.1 and No.2 22 kV Buses at ZSS FE (Footscray East)

Report Number: CM-2606b-18 Test Date: 15 Nov 2018

Tested For :	Jemena Asset Management P L Level 16, 567 Collins Street Melbourne 3000
Customer PO No. :	4100241647
Job No. :	110842975
Location :	ZSS FE (Footscray East)
Items Tested :	**No.1 and No.2 Buses** Make : Metro Vickers Serial Number : N/A Voltage : 20 kV Type : SB14
Nature of Tests :	1 Insulation Resistance Measurements 2 Dielectric Dissipation Factor & Capacitance Measurements 3 Partial Discharge Measurements

Comments :

FE No.1 22 kV Bus

Insulation Resistance & Polarisation Index

IR results have decreased from 21.7, 22.8 and 27.5 GΩ in 2008 to 10.0, 10.8 and 9.28 GΩ in 2018 respectively for the three phases (refer to test report CM-1850-08). The IR results are still considered satisfactory.

PI results have decreased from 1.7, 2.0 and 2.0 in 2008 to 1.4, 1.6 and 1.4 in 2018 for the three phases (refer to test report CM-1850-08).

Dielectric Dissipation Factor & Capacitance Measurements

DDF results have increased from 1.31, 1.37 and 1.10 % (normalised to 20 °C) in 2008 to 1.73, 1.83 and 1.47 % (normalised to 20 °C) in 2018 respectively for the three phases. The DDF results are still considered satisfactory.

Capacitance has increased by 0.20, 0.40 and 0.57 % from 2008 on each phase respectively.

See the next page for further comments

This report consists of 12 pages.

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jk m/jk Checked by: ky

K Yew
AUTHORISED SIGNATORY

DATED: *21 Dec 2018*

SELECT SOLUTIONS

Comments (Cont'd) :

Partial Discharge Measurements

The magnitude of the partial discharge (PD) above the service voltage level has increased on all phases from the previous measurements in 2008 (refer to test report CM-1850-08). However, both inception and extinction voltage levels remain similar to the previous measurements in 2008 and are above service voltage level.

Phase Resolved PD (PRPD) patterns indicate that the discharges occurred internally.

<u>FE No.2 22 kV Bus</u>

Insulation Resistance & Polarisation Index

IR results have decreased from 43.2, 39.3 and 38.0 GΩ in 2008 to 19.9, 20.2 and 20.9 GΩ in 2018 respectively for the three phases (refer to test report CM-1851-08). The IR results are still considered satisfactory.

PI results have decreased from 2.1, 2.5 and 2.0 in 2008 to 1.53, 1.85 and 1.55 in 2018 respectively for the three phases (refer to test report CM-1851-08).

Dielectric Dissipation Factor & Capacitance Measurements

DDF results have increased from 1.14, 1.31 and 1.09 % (normalised to 20 °C) in 2008 to 1.25, 1.40 and 1.16 % (normalised to 20 °C) in 2018 respectively for the three phases. The DDF results are still considered satisfactory.

Capacitance has increased by 8.8, 7.7 and 7.1 % from 2008 on each phase respectively.

Partial Discharge Measurements

PD results are similar to the previous measurements in 2008 (refer to test report CM-1851-08).

Phase Resolved PD (PRPD) patterns indicate that the discharges occurred internally.

AusNet Transmission Group Pty Ltd
Select Solutions
308 Hyde Street,
Yarraville, Victoria 3013

A.C.N. 079 798 173
A.B.N. 78 079 798 173
Telephone: (03) 9688 1400
Facsimile : (03) 9688 1414

TEST REPORT

Condition Monitoring on No.1 22 kV Bus at ZSS FW (Footscray West)

Report Number: CM-2607b-18 Test Date: 13 Nov 2018

Tested For :	Jemena Asset Management P L PO Box 16015 Melbourne VIC 3000
Customer PO No. :	4100241647
Job No. :	110842976
Location :	ZSS FW (Footscray West)
Item Tested :	**No.1 22 kV Bus** Make : Metro Vickers Serial Number : N/A Voltage : 20 kV Type : SB14
Nature of Tests :	1 Insulation Resistance Measurements 2 Dielectric Dissipation Factor & Capacitance Measurements 3 Partial Discharge Measurements

Comments :

Insulation Resistance & Polarisation Index

IR results have decreased from 43.0, 59.4 and 29.3 GΩ in 2012 to 24.2, 28.3 and 19.6 GΩ in 2018 respectively for the three phases (refer to test report CM-0314-12). The IR results are still considered satisfactory.

PI results have decreased from 2.0, 2.8 and 2.0 in 2012 to 1.7, 2.0 and 1.7 in 2018 respectively for the three phases (refer to test report CM-0314-12).

Dielectric Dissipation Factor & Capacitance Measurements

DDF results have increased from 0.55, 0.76 and 0.69 % (normalised to 20 °C) in 2012 to 0.63, 0.84 and 0.77 % (normalised to 20 °C) in 2018 respectively for the three phases. The DDF results are still considered satisfactory.

Capacitance has increased by 8.7, 7.3 and 6.7 % from 2012 on each phase respectively.

See the next page for further comments

This report consists of 7 pages.

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jk rn tp/tp Checked by: ky

K Yew
AUTHORISED SIGNATORY

DATED: *21 Dec 2018*

SELECT SOLUTIONS

Comments (Cont'd) : **Partial Discharge Measurements**

The magnitudes of partial discharge (PD) at 19 kV and 22 kV for B Phase are higher than those obtained in 2012. Inception and extinction voltages for all phases are similar to those obtained in 2012 (refer to test report CM-0314-12). Phase Resolved PD (PRPD) patterns indicate that the discharges occurred internally.

AusNet Transmission Group Pty Ltd
Select Solutions
308 Hyde Street,
Yarraville, Victoria 3013

A.C.N. 079 798 173
A.B.N. 78 079 798 173
Telephone: (03) 9688 1400
Facsimile : (03) 9688 1414

TEST REPORT

Condition Monitoring on No.2 22 kV Bus at ZSS FW (Footscray West)

Report Number: CM-2608b-18 Test Date: 13 Nov 2018

Tested For :	Jemena Asset Management P L PO Box 16015 Melbourne VIC 3000
Customer PO No. :	4100241647
Job No. :	110842976
Location :	ZSS FW (Footscray West)
Item Tested :	**No.2 22 kV Bus** Make : Metro Vickers — Serial Number : N/A Voltage : 20 kV Type : SB14
Nature of Tests :	1 Insulation Resistance Measurements 2 Dielectric Dissipation Factor & Capacitance Measurements 3 Partial Discharge Measurements

Comments :

Insulation Resistance & Polarisation Index

IR results have decreased from 12.9, 24.0 and 12.1 GΩ in 2012 to 6.5, 8.4 and 6.5 GΩ in 2018 respectively for the three phases (refer to test report CM-0314-12). The IR results are still considered satisfactory.

PI results have decreased from 1.5, 2.2 and 1.6 in 2012 to 1.3, 1.5 and 1.4 in 2018 for the three phases (refer to test report CM-0314-12).

Dielectric Dissipation Factor & Capacitance Measurements

DDF results have increased from 0.83, 0.88 and 0.74 % (normalised to 20 °C) in 2012 to 1.04, 1.07 and 0.93 % (normalised to 20 °C) in 2018 respectively for the three phases. The DDF results are still considered satisfactory.

Capacitance has increased by 7.5, 6.3 and 5.4 % from 2012 on each phase respectively.

See the next page for further comments

This report consists of 7 pages.

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Checked by: ky

K Yew
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DATED: *21 Dec 2018*

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Comments (Cont'd) : **Partial Discharge Measurements**

C Phase has higher partial discharge results at 19 kV and 22 kV than the other two phases. The same trend was observed in the previous results of 2012 (refer to test report CM-0314-12). Phase Resolved PD (PRPD) patterns indicate that the discharges occurred internally.

AusNet Transmission Group Pty Ltd
Select Solutions
308 Hyde Street,
Yarraville, Victoria 3013

A.C.N. 079 798 173
A.B.N. 78 079 798 173
Telephone: (03) 9688 1400
Facsimile : (03) 9688 1414

TEST REPORT

Condition Monitoring on No.3 22 kV Bus at ZSS FW (Footscray West)

Report Number: CM-2929b-18 Test Date: 14 Nov 2018

Tested For :	Jemena Asset Management P L Level 16, 567 Collins Street Melbourne 3000
Customer PO No. :	4100241647
Job No. :	110842976
Location :	ZSS FW (Footscray West)
Item Tested :	**No.3 22 kV Bus** Make : Metro Vickers Serial Number : N/A Voltage : 20 kV Type : SB14
Nature of Tests :	1 Insulation Resistance Measurements 2 Dielectric Dissipation Factor & Capacitance Measurements 3 Partial Discharge Measurements

Comments :

Insulation Resistance & Polarisation Index

IR results have decreased from 70.4, 87.8 and 84.1 GΩ in 2012 to 17.5, 20.8 and 18.9 GΩ in 2018 respectively for the three phases (refer to test report CM-0523-12). The IR results are still considered satisfactory.

PI results have decreased from 2.4, 3.4 and 3.2 in 2012 to 1.45, 1.68 and 1.63 in 2018 respectively for the three phases (refer to test report CM-0523-12).

Dielectric Dissipation Factor & Capacitance Measurements

DDF results have changed from 1.35, 1.27 and 1.00 % (normalised to 20 °C) in 2012 to 1.24, 1.37 and 0.98 % (normalised to 20 °C) in 2018 for the three phases. The DDF results are still considered satisfactory.

Capacitance has increased by 8.5, 7.0 and 5.8 % from 2012 on each phase respectively.

See the next page for further comments

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jk m/jk

Quote No: TS18/P4538 Rev 2
Checked by: ky

K Yew
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DATED: *21 Dec 2018*

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Comments (Cont'd) : **Partial Discharge Measurements**

The magnitude of the partial discharge (PD) above the service voltage level has increased significantly on all phases from the previous measurements in 2012 (refer to test report CM-0523-12). Phase Resolved PD (PRPD) patterns indicate that the discharges occurred internally.

As mentioned previously in 2012, the PD inception and extinction levels for A Phase (Red Phase) are low (Inception at 14.0 kV, Extinction at 9.5 kV). This indicates that PD may appear during normal operating conditions. More frequent monitoring should be performed on this Bus.

Appendix D
Plant Defect Report

D1. PLANT DEFECT REPORT

Plant Defect Report – JEN0015

Apparatus :	Metro Vickers type SB14 22kV CB
Originating Document:	N/A
Date of Report :	9th August 2012
Serial No. :	0880281
Type. :	**SB14**
Circuit :	FE5 feeder 22KV CB
Date of Observation :	20th July 2012
Time :	
Station :	FE – Footscray East
Reported :	P.Truong/S.Bongetti
Subject :	worn Hold On Catch

Summary

On the 23rd July 2012, auto-reclose on the 22kV CBs were suppressed at FE for planned works on site to commission the auto-reclose on WMTS-FE No.2 66kV line.

During the day, FE5 CB tripped due to fault however attempts to reclose the CB were unsuccessful.

Investigation

Fitters were sent to site to investigate. The CB was operated multiple times to test its functionality. When the CB was manually "closed", it was observed that the "trip toggle pivot pin" would not securely fit into the "Hold on Catch" and the CB was unable to remain in the "close" position. This was also observed when tapping or agitating the mechanism caused the CB to trip.

Closer inspection of the "Hold on Catch" indicated that it was badly worn and there were signs of previous welding repairs on the "Hold on Catch".

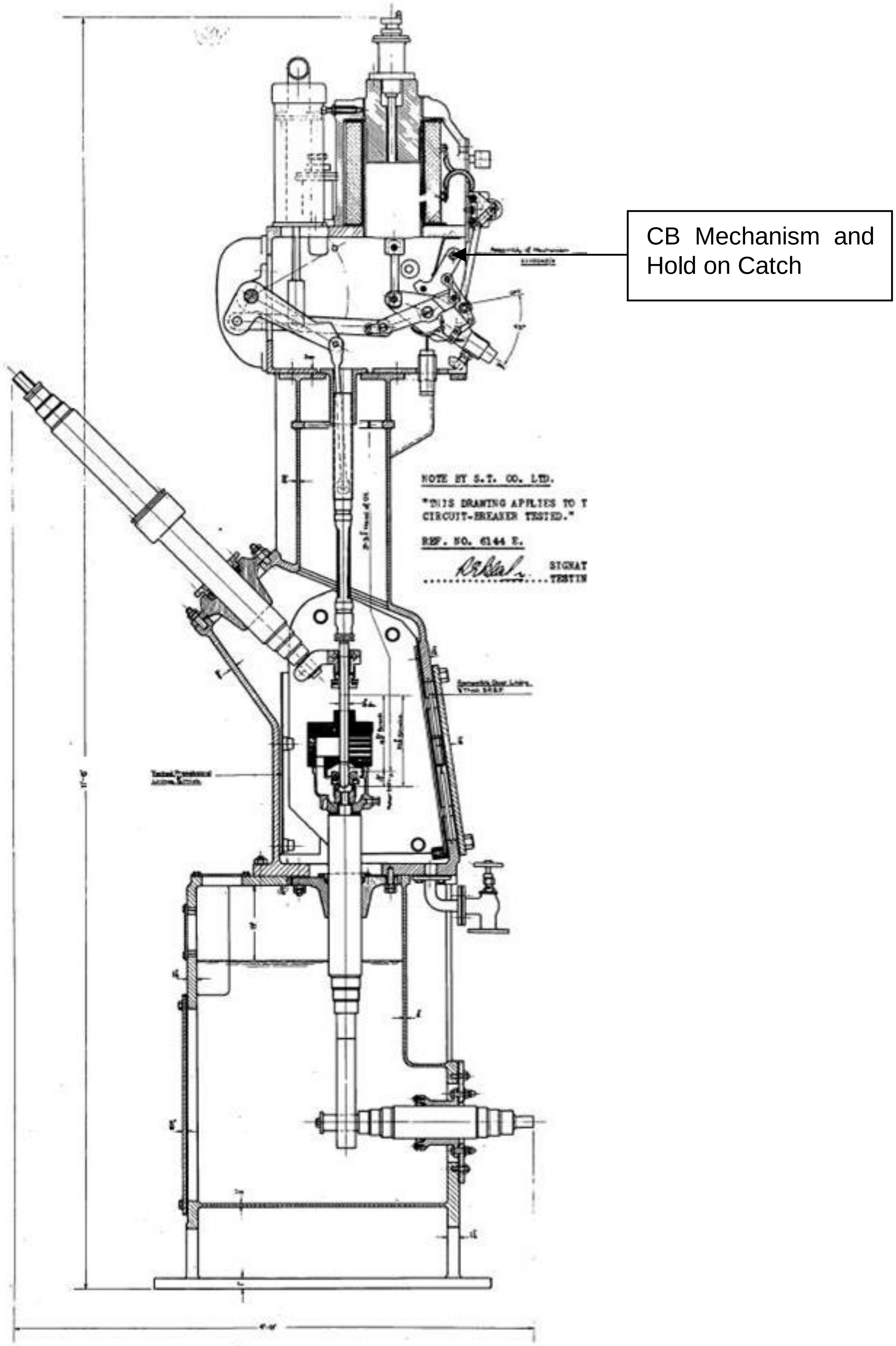
Action Taken

Feeder FE5 has been transferred to an adjacent feeder via the transfer bus.

FE5 CB will remain out of service until the "Hold on Catch" plate can be replaced.

Photo 1: Circuit Breaker Mechanism

Photo 2: Worn Hold on Catch



Metropolitan Vickers Type SB14 22kV Circuit Breaker

Recommendation

- Disassemble the spare CB at FE and remove the “Hold on Catch”.
- Replace the worn “Hold on Catch” on feeder FE5 CB using the one obtained from the spare CB. Refer to the manufacturer’s manual for the CB and perform all necessary adjustments.
- Perform timing tests using the Cincinnati analyser and functionally operate the CB to confirm successful operation.
- The Metropolitan Vickers Type SB14 CB is similar to the AEI Type LG4C CB. During maintenance of the SB14 CB or LG4C CB, the Hold on Catch needs to be inspected for excessive wear. If the CB fails to latch close, then the Hold on Latch may need to be replaced.
- Repair the hold on latch removed from Feeder FE5 CB.

Appendix E
22kV Pin and Cap Insulator Failure

E1. 22KV PIN AND CAP INSULATOR FAILURE

Extract: Electricity Primary Plant Asset Class strategy

All outdoor pin and cap type insulators under tension or shear force at various zone substations across the JEN electricity network require replacing. There has been a number of failures across other utilities both nationally (incl. Victoria) and internationally. Although only two ABB isolators with cracked porcelain have been found at zone substations BD and CN, there have been several failures in the distribution network. In each case throughout the JEN distribution network, the porcelain insulator has broken and was either found to be hanging from the HV conductor tail, or in some circumstances has resulted in the isolator blade collapsing during field switching.

In 2011 a pin and cap insulator failed in a Victorian electricity network. The failure caused the insulator to separate from its support structure, resulting in the transfer bus isolator together with the pin of the insulator and the tubular bus to be left unsupported. As a result, the tubular bus has bent due to cantilever forces, leaving the pin, isolator and tube hovering approximately 1 metre from the ground. It remained live and was discovered by personnel carrying out ground maintenance.

As Porcelain has very high compressive strength (80,000 psi), sixteen times greater than its tensile strength (5,000psi). Cap and pin insulators have a design flaw which can subject them to tensile forces generated between two or more porcelain shells from two possible sources which can lead to cracking and eventual failure: “growth” within the cement joint and thermal expansion differences. Station post insulators are designed to take advantage of porcelain’s compressive strength by avoiding conditions which put them in tension. Each station post section employs a large, single piece of porcelain in contrast to the cap and pin that is composed of one to three individual porcelain shells nested together and joined by cement. The simpler design and the use of fewer cemented joints means that station posts are more rigid and exhibit less deflection under load than cap and pin insulators, which is an important feature in switch applications.

Figure 6: Failed Pin & Cap Insulator

Live 22kV bus section approximately 1m above ground level. Attached to pin which had separated from an insulator

22kV insulator pin separated from porcelain and hanging from live bus

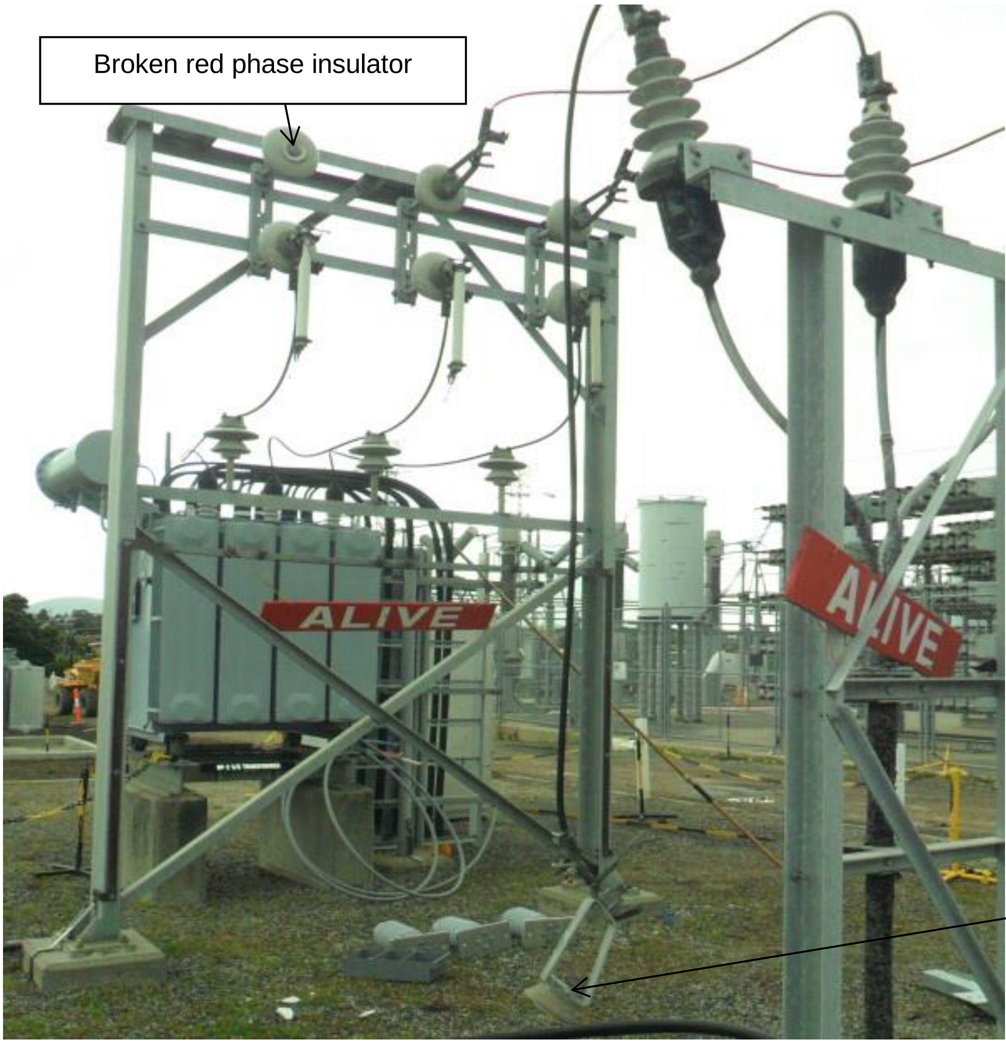
22kV Electric Shock - Powdered Fuse Insulator Failure

Date:	30/10/13	Number	SG 2013039
Issued by:	HSEQ Team	Distribution:	All SP AusNet

Summary of event:

During planned cable cut over work at Rowville Terminal Station on the 29/10/13 a stations operator was operating three phase 22kv Powder filled fuse units. After opening the blue and white phases he opened the red phase. As he opened the red phase fuse unit the insulator broke, dropping the conductor towards the operator.

The operator fell to the ground and the conductor made contact with his right hand. Project and delivery partner employees who witnessed the incident made the area safe and provided assistance. An ambulance was immediately called to the site. WorkSafe and ESV were notified.



Extend of injury/damage:

The operator suffered a 22kV electric shock and has minor entry and exit wounds to his right hand and foot. He has been released from hospital this afternoon after having been under observation overnight.

Contributing Factors and Corrective Action:

A full investigation is underway and key learning's will be shared at completion of the investigation.

In the interim:

- Any fuse units where the conductor can fall to ground if an insulator fails (same or similar configuration to that pictured) must not be operated and reported to Regional Delivery Managers.

Appendix F
Zone Substation FE: Single Line Diagram

F1. ZONE SUBSTATION FE: SINGLE LINE DIAGRAM