Jemena Electricity Networks (Vic) Ltd

Replace Coburg North (CN) Zone Substation Switchgear

2022 and 2023 Business Case

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Owning Functional Area

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PREFACE

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

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1. EXECUTIVE SUMMARY

Paper Summary

- The switchgear at Zone Substation CN (Coburg North) is at risk of failure due to its age and poor condition and poses serious safety and security of supply concerns.
- To manage the risks this project involves the replacement of three outdoor 22kV buses with modern arc fault contained indoor switchgear, replacement of the brown pin and cap type insulators, replacement of two 66kV bus tie CBs and the addition of a new 66kV line CB.
- The project will be completed during 2023 at a cost of $7.765M (total project cost, real $2019).

1.1 BUSINESS NEED

Zone Substation (**ZSS**) Coburg North (**CN**) consists of three 66kV/22kV power transformers, three 66kV Circuit Breakers (**CB**s), three capacitor banks and eleven 22kV feeders which supply around 24,000 JEN customers. Refer to Appendix A2 for the Single Line Diagram.

The AEI LG4C (1-2 66kV bus tie) CB, estimated to be 51 years old, represents a family of breakers with a history of mechanical failure and catastrophic bushing failures. Catastrophic failure of the primary insulation risks the safety of employees and security of customer supply. In 2015 at ZSS Footscray East (**FE**) on the 1-2 66kV bus tie, CB one of the bushings was replaced with a spare due to degradation of the insulation identified during condition monitoring testing. Furthermore, the CB controls, currently operating at 240V DC, need to operate at 110V DC, which is the current JEN standard. This type of CB is no longer supported by the manufacturer and spare components are no longer available.

The ASEA HLC (2-3 66kV bus tie) CB, estimated to be 28 years old, is oil filled, maintenance intensive and no longer supported by the manufacturer. The CB controls, currently operating at 240V DC, need to operate at 110V DC, which is the current JEN standard. The replacement of this CB is also planned with this project as spare components are no longer available.

The ABB EDF (Sub CS 66kV FDR) CB is estimated to be 18 years old. The CB controls, currently operating at 240V DC, need to operate at 110V DC, which is the current JEN standard. Considering this is a relatively modern CB, the operating mechanism can be modified from 240V DC to 110V DC controls.

The outdoor 22kV CBs manufactured by Email (type 345GC), Siemens (type 3AF) and Crompton Greaves (type 30-SFGP-25A) are estimated to be 51, 32 and 20 years old respectively. The condition of the Email 345GC CBs has degraded to a point where employee safety, reliability and security of customer supply will be affected. The Email 345GC CBs are no longer supported by the manufacturer and mechanism spare parts have run out.

The 22kV Email type 345GC CB is an outdoor CB located within various ZSS on JEN's distribution network. There are various issues that have been recorded for this type of CB:

- History of compound leaks from the bushings;
- Main contact pull rod failures;
- Maintenance intensive (maintenance frequency increased from 12 years to 6 years), and
- Worn Pull Rod guides.

New failure modes are emerging as the asset is continuing to age beyond the expected serviceable life. Failure of some existing components can be mitigated by engineering new components, but this process is costly and does not mitigate the age or age-related failure of other components within the CB.

All existing outdoor 22kV CBs at CN are non-compliant with current switchgear standards for electrical arc fault containment standards. This presents a health and safety risk to JEN personnel. In the event that the insulation fails, the resulting electrical arc and pressure wave will not be contained within the CB, and consequently, the risk to employee health and safety is elevated.

In addition to the CB issues, there are known defects with the outdoor 22kV transfer bus. The pin and cap 22kV insulators are prone to failure from moisture ingress and subsequent formation of corrosion at the point where the pin is cemented into the insulator. This causes cracks to form in the porcelain leading to High Voltage (**HV**) connections that are no longer supported. There have been two serious incidents caused by this failure within other electricity businesses. 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 outdoor switchgear; however, the new proposed 22kV switchgear provides an opportunity to remove the outdoor 22kV transfer buses thus removing the associated safety risk.

There are five current issues (Refer section 2.2 for details) associated with the CN assets. The following options to address the issues have been considered.

1. Do Nothing
2. Increased Maintenance and Monitoring
3. 22 kV and 66 kV Switchgear Refurbishment
4. Transfer Load
5. Replace 22kV (indoor) and 66kV CBs
6. Replace 22kV (outdoor) and 66kV CBs
7. Non-network solutions

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

Table OV–1-1: Options Analysis

Condition Issue	**Option1** Do Nothing	**Option2** Increased Maint. & Monitoring	**Option 3** Switchgear Refurb	**Option 4** Load Transfer	**Option 5** Replace 22kV CBs (indoor) & 66kV CBs	**Option 6** Replace 22kV CBs (outdoor) & 66kV CBs	**Option 7** Non-network Solutions
Issue 1 Switchgear Condition	○	○	◑	●	●	●	●
Issue 2 Non arc fault Containment	○	○	○	●	●	○	●

Condition Issue	Option1 Do Nothing	Option2 Increased Maint. & Monitoring	Option 3 Switchgear Refurb	Option 4 Load Transfer	Option 5 Replace 22kV CBs (indoor) & 66kV CBs	Option 6 Replace 22kV CBs (outdoor) & 66kV CBs	Option 7 Non-network Solutions
Issue 3 Lack of Spare Parts	○	○	○	●	●	●	●
Issue 4 22 kV Insulators	○	○	○	●	●	●	●
Issue 5 66 kV CBs	○	○	◑	●	●	●	●
Technically & Financially Viable	○	○	○	○	●	○	○

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

Refer to Section 3 for a detailed discussion on options analysis.

The least lifecycle cost option in the best interest of the customer that addresses the aforementioned prominent risks is to replace the outdoor 22kV switchgear with indoor 22kV switchgear which includes a new building.

The new switchgear will conform to current Australian Standards and will mitigate safety concerns, maintain reliability and security of customer supply.

The 1-2 and 2-3 66kV bus tie CBs will be replaced with new dead tank CBs as per current JEN standards.

1.2 RECOMMENDATION

It is recommended that Option 5 be adopted and all three outdoor 22kV buses and associated CBs, two 66kV bus tie CBs be replaced with new modern equivalents, a new 66kV line CB installed and a new building installed to current standards. 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.

This option is considered prudent and efficient, having a positive net present value and is the preferred option, and will address all know issues. This option addresses all the condition issues identified in Section 2.2, and the risk to network performance would be minimised.

The new switchgear will conform to current Australian Standards and will mitigate safety concerns, and maintain, reliability and security of customer supply.

The total cost of this option is estimated at $7.765M (total project cost, real $2019), and the project would commence in 2022. The switchgear will then be over 55 years old and beyond its design life.

1.3 REGULATORY CONSIDERATIONS

The objective of the project is to determine the most appropriate strategy for the nominated assets to maintain customer supply reliability at CN, given their current condition. 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), the Victorian Electricity Distribution Code.

Seven options have been explored in the Options Analysis in Section 3 of this document to identify the best possible option. The options have been benchmarked against risks to ensure the health, safety and reliability issues were addressed. Fundamentally risk, cost and value are the primary drivers however, the best value option, not the cheapest is recommended.

1.4 FINANCIAL INFORMATION

1.4.1 FORECAST EXPENDITURE AND BUDGET SUMMARY

This business case proposes a total investment of $7.765M (total project cost, real $2019) and requires Managing Director's (Band B) approval under the SGSPAA DFA Manual, Annex 3.

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

This project is required to be commissioned by 2023.

Table 1-2: Project Budget Information

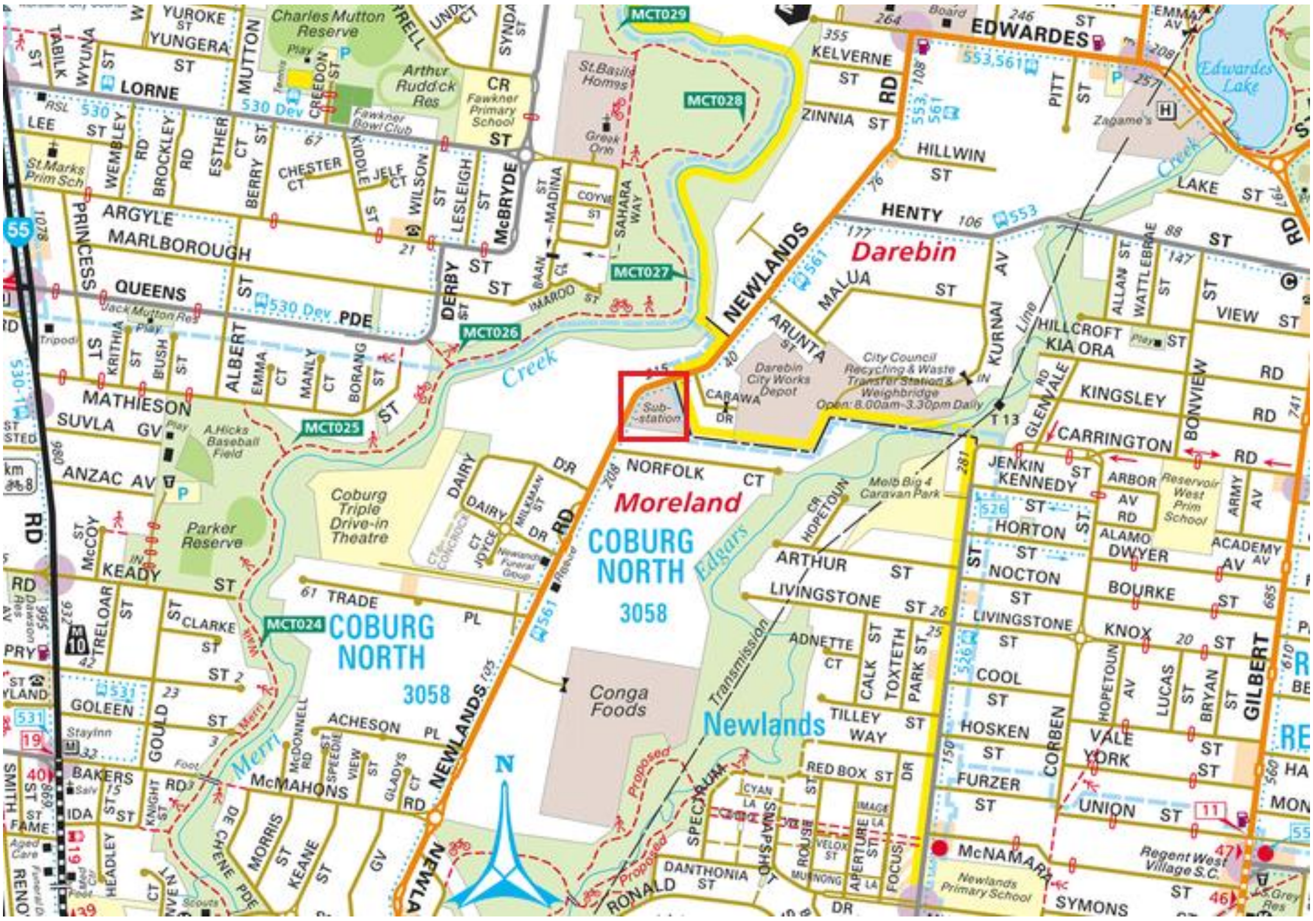
Business Case Spend ($'000s, 2019)	Total
CAPEX Spend	6,761
Overhead Recovery	1,004
Total Business Case Value	**7,765**

2. BACKGROUND

The purpose of this document is to set out the business case for the ZSS CN CB replacement project, including its regulatory treatment in the JEN building block regulatory proposal and its alignment with JEN's Electricity Primary Plant Asset Class Strategy – JEN PL 0061.

ZSS CN was commissioned in 1976 and is located to the north of the Melbourne CBD, at the corner of Newlands Road and Norfolk Court in Coburg North (Melways ref: 18 A7) as shown in Figure 2–1.

Figure 2–1: Location of ZSS CN



ZSS CN consists of three 66kV/22kV power transformers rated at 30MVA each and has eight 22kV feeders which supply 24,000 JEN customers. Refer to Appendix A2 for the Single Line Diagram.

CN is an outdoor 22kV switchyard consisting of Email 345GC bulk oil CBs and Siemens 3AF vacuum CBs. The Email 345GC CBs are estimated to be 53 years old.

2.1 ASSET DETAILS

2.1.1 22KV ASSET DETAILS

The 22kV switchgear installed at CN is briefly described in Table 2-1 and Figure 2–2. The 345GC CBs are outdoor dead tank bulk oil CBs. The load break mechanism is via heavy copper contacts that are suspended via wood pull rods. The 345GC CBs are installed at ZSS Airport West (**AW**), Broadmeadows (**BD**) and CN.

Table 2-1: CN switchgear Details

Designation	Make	Type	Voltage	Current	SECV Spec No.	Year of Manufacture
NO.1 TRANS, NO.2 TRANS, NO.1 CAP BANK, NO.2 CAP BANK, 1-2 BUS TIE, FDRs CN2, CN3, CN4, CN5, CN6, CN7, CN8	EMAIL	345GC	22kV	1,200A	64-65/58 65-66/390	1967
NO.3 TRANS, NO.3 CAP BANK, 2-3 BUS TIE, FDRs CN1, CN9, CN10	Siemens	3AF	22kV	1,250A, 630A	83/532	1986
FDR CN11	Crompton Greaves	30-SFGP-25A	22kV	1,250A	Q98830232	1998

Figure 2–2: CN 22kV Switchgear

There have been 26 recorded defects associated with the CN Email 345GC 22kV switchgear and recorded in JSAP (JEN's Maintenance Management System). In addition, 32 defects have occurred at ZSS AW (Airport West) and 24 defects have been reported for ZSS BD (Broadmeadows). AW, BD and CN all have the Email 345GC switchgear on the JEN Network. However, the CB replacement at CN is being considered a priority and the CB replacements at AW and BD will be addressed in separate subsequent business cases. AW also has the Crompton Greaves 30-SFGP-25A CBs. Neither AW nor BD has the Siemens 3AF CBs. These defects are shown in Table 2-2,

Table 2-3 and

Table 2-4 below.

It has been found that the 345GC CBs suffer from several issues. The predominant issue is bushing defects. The bushings have been found to be leaking pitch and a program was initiated to refurbish all bushings on the 345GC CBs on the JEN. In recent years the main contact pull rods have experienced failures. These pull rods were made from Permali wood, which is no longer available. These pull rods have been replaced with fibre glass pull rods. In 2014 a project was initiated to replace pull rods with fibre glass pull rods on all transformer and cap bank CBs on JEN.

There has been no recorded defects on the Siemens 3AF CBs. However, due to excessive switching duties, on the cap bank CBs in particular, some of the Siemens 3AF cap bank CBs have had their interrupters replaced.

The Crompton Grieves CBs have a history of ongoing issues. The main issue was related to SF6 leaks from the interrupter poles. A number of CBs on JEN have had their interrupters refurbished. This is an ongoing issue and will only be resolved with the replacement of the CBs.

Table 2-2: CN 345GC Switchgear Defect History

Date	CN Asset	Defect	Remedy
03/04/2008	1-2 22KV BUS TIE CB	Failed to Operate	Investigate, repair
29/08/2008	FDR CN 8 CB	Bushing Defect	Investigate, repair
29/08/2008	NO.1 TRANS 22KV CB	Bushing Defect	Investigate, repair
01/09/2008	NO.3 TRANS 22KV CB	Worn Interrupter	Investigate, replace
01/09/2008	2-3 22KV BUS TIE CB	Worn Interrupter	Investigate, replace
23/09/2010	FDR CN 6 CB	Bushing Defect	Investigate, repair
11/05/2011	FDR CN 6 CB	Bushing Defect	Investigate, repair
03/12/2012	NO.2 TRANS 22KV CB	Leaking Oil	Investigate, oil top up, and/or tightened bolts
09/09/2013	FDR CN 5 CB	Bushing Defect	Investigate, repair
09/09/2013	1-2 22KV BUS TIE CB	Bushing Defect	Investigate, repair
13/12/2013	NO.1 CAP BANK CB	Failed to Operate	Investigate, repair
03/01/2014	FDR CN 11 CB	Failed to Operate	Investigate, repair
14/01/2014	NO.3 CAP BANK	Failed to Operate	Investigate, repair
19/03/2014	FDR CN 10 CB	CB Trip Free	Investigate, repair
01/09/2014	FDR CN 4 CB	Thermal Defect	Investigate, repair
02/09/2014	FDR CN 8 CB	Bushing Defect	Investigate, repair

Date	CN Asset	Defect	Remedy
13/07/2015	NO.3 CAP BANK CB	Failed to Operate	Investigate, repair
15/02/2016	FDR CN 10 CB	CB Trip Free	Investigate, repair
16/02/2016	NO.2 TRANS 22KV CB	CB Slow Trip	Investigate, repair
25/07/2017	FDR CN 3 CB	CB Slow Trip	Investigate, repair
25/07/2017	FDR CN 5 CB	CB Slow Trip	Investigate, repair
21/08/2017	FDR CN 5 CB	Bushing Defect	Investigate, repair
10/09/2018	FDR CN 8 CB	Bushing Defect	Investigate, repair
10/09/2018	NO.1 TRANS 22KV CB	Bushing Defect	Investigate, repair
10/09/2018	NO.1 CAP BANK CB	Bushing Defect	Investigate, repair
10/09/2018	NO.2 TRANS 22KV CB	Bushing Defect	Investigate, repair

Table 2-3: AW 345GC Switchgear Defect History

Date	AW Asset	Defect	Remedy
3/04/2008	FDR AW 11 CB	Leaking Oil	Investigate, oil top up, and/or tightened bolts
26/06/2008	FDR AW 2 CB	Leaking Oil	Investigate, oil top up, and/or tightened bolts
18/12/2008	FDR AW 4 CB	Bushing Defect	Investigate, repair
18/12/2008	FDR AW 12 CB	Bushing Defect	Investigate, repair
21/12/2009	FDR AW 8 CB	Bushing Defect	Investigate, repair
21/12/2009	FDR AW 11 CB	Leaking Oil	Investigate, oil top up, and/or tightened bolts
21/12/2009	NO.1 TRANS 22KV CB	Bushing Defect	Investigate, repair
21/12/2009	FDR AW 12 CB	Bushing Defect	Investigate, repair
19/08/2010	FDR AW 12 CB	Bushing Defect	Investigate, repair
19/12/2011	NO.1 TRANS 22KV CB	CB Trip Free	Investigate, repair
06/12/2012	FDR AW 14 CB	Viewing Window Defect	Investigate, repair/replace
6/12/2012	FDR AW 14 CB	Viewing Window Defect	Investigate, repair/replace
7/01/2013	1-2 22KV BUS TIE CB	Bushing Defect	Investigate, repair
19/12/2013	NO.4 TRANS 22KV CB	CB Slow Trip	Investigate, repair
02/01/2014	FDR AW 11 CB	CB Slow Trip	Investigate, repair
02/01/2014	FDR AW 14 CB	CB Slow Trip	Investigate, repair
23/04/2015	NO.2 TRANS 22KV CB	Failed to Operate	Investigate, repair
20/11/2015	NO.1 TRANS 22KV CB	CB Slow Trip	Investigate, repair
02/02/2016	NO.1 CAP BANK CB	Bushing Defect	Investigate, repair
02/02/2016	NO.2 TRANS 22KV CB	Bushing Defect	Investigate, repair

Date	AW Asset	Defect	Remedy
26/05/2017	FDR AW 9 CB	Bushing Defect	Investigate, repair
09/09/2017	NO.3 TRANS 22KV CB	Bushing Defect	Investigate, repair
14/11/2017	FDR AW 11 CB	Viewing Window Defect	Investigate, repair
20/11/2017	FDR AW 12 CB	Cable Term. Defect	Investigate, repair/replace
04/12/2017	FDR AW 6 CB	Bushing Defect	Investigate, repair
30/01/2018	FDR AW 6 CB	Bushing Defect	Investigate, repair
30/01/2018	FDR AW 9 CB	Bushing Defect	Investigate, repair

Table 2-4: BD 345GC Switchgear Defect History

Date	BD Asset	Defect	Remedy
16/07/2008	FDR BD 14 CB	Thermal Defect	Investigate, repair
24/07/2008	NO.2 CAP BANK CB	Bushing Defect	Investigate, repair
19/12/2008	FDR BD 3 CB	Bushing Defect	Investigate, repair
19/12/2008	FDR BD 7 CB	Bushing Defect	Investigate, repair
19/12/2008	FDR BD 9 CB	Bushing Defect	Investigate, repair
19/12/2008	FDR BD 10 CB	Bushing Defect	Investigate, repair
19/12/2008	FDR BD 11 CB	Bushing Defect	Investigate, repair
21/12/2009	FDR BD 11 CB	Bushing Defect	Investigate, repair
20/12/2010	FDR BD 6 CB	Bushing Defect	Investigate, repair
14/12/2011	FDR BD 7 CB	Bushing Defect	Investigate, repair
14/12/2011	FDR BD 7 CB	Bushing Defect	Investigate, repair
11/05/2012	1-2 22KV BUS TIE CB	CB Trip Free	Investigate, repair
11/05/2012	1-2 22KV BUS TIE CB	CB Trip Free	Investigate, repair
07/12/2012	1-2 22KV BUS TIE CB	Bushing Defect	Investigate, repair
12/12/2012	FDR BD 11 CB	Leaking Oil	Investigate, oil top up, and/or tightened bolts
07/03/2013	FDR BD 3 CB	Bushing Defect	Investigate, repair
01/01/2015	1-2 22KV BUS TIE CB	Bushing Defect	Investigate, repair
11/09/2015	FDR BD 3 CB	Failed to Open/Close	Investigate, repair
08/08/2016	FDR BD 2 CB	Bushing Defect	Investigate, repair
19/08/2016	No.4 TRANS 22KV CB	Bushing Defect	Investigate, repair
03/11/2016	NO.2 CAP BANK CB	Failed to Open/Close	Investigate, repair
15/11/2016	NO.2 CAP BANK CB	Failed to Open/Close	Investigate, repair
26/03/2017	FDR BD 13 CB	Bushing Defect	Investigate, repair

Date	BD Asset	Defect	Remedy
21/05/2018	FDR BD 4 CB	Bushing Defect	Investigate, repair

The 22 kV Transfer Bus installed at CN is briefly described in Table 2-5 and Figure 2–3: CN 22 kV Transfer BusFigure 2–3.

Table 2-5: CN 22 kV Transfer Bus Details

Designation	Make	Voltage	Current	SECV Spec No.	Year of Manufacture
22 kV Transfer Bus and Connections	SECV	22 kV	995A	N/A	1967

Figure 2–3: CN 22 kV Transfer Bus

There have been two recent incidents associated with the failure of 22 kV pin and cap type insulators within Victoria as follows:

1. In circumstances similar to the arrangement in Figure 2–3, an insulator had sheared from the pin and resulted in the bus dropping to 1 m above ground level. The bus remained alive and was found by an employee.
2. 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.

2.1.2 66KV ASSET DETAILS

The 66kV switchgear installed at CN is briefly described in Table 2-6 and Figure 2–4.

Table 2-6: CN 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	1,600A	64-65/199	1967
2-3 66kV Bus Tie CB	ASEA	HLC 72.5	66kV	1,600A	82/389	1990
SUB CS FDR	ABB	EDF SK1-1	66kV	2,000A	-	1990

Figure 2–4: CN 1-2 66kV Bus Tie CB

There have been no recorded defects on the 1-2 66 kV Bus Tie CB on the JEN network; however, there are records of this type of CB, in the Victorian Electricity Industry, with a history of defects and catastrophic failures. Please refer to Section 2.2.1, dot point 5 for further details.

The 2-3 66kV bus tie CB, an ASEA HLC72.5 suffers from water in oil issues. This is due to the “free-breathing” design of the CB, which allows moisture to enter the CB in the humid and wet season. This results in the accumulation of significant volume of ‘free’ water (i.e. water below the oil) that must be drained from the CB stacks at each maintenance outage.

The ABB EDF SK1-1 is a modern design SF6 insulated CB. No defects have been recorded for the SUB CS FDR CB.

2.2 ASSET RISK ANALYSIS

2.2.1 ASSET CONDITION ISSUES

Five current issues associated with the CN assets have been identified and are discussed below:

1. **Outdoor 22kV CB's condition has degraded to a point where employee safety, reliability and security of customer supply will be affected.**

   The outdoor 22kV CBs manufactured by Email (345GC), Siemens (3AF) and Crompton Greaves (30-SFGP-25A) are estimated to be 51, 32 and 20 years old respectively. Although some CBs/switchboards have continued to operate satisfactorily for over 50 years, a 50-year-old CB is approaching the end of its practical life due to mechanical wear, lack of spare parts, insulation degradation and non-compliance to modern arc fault containment safety standards.

   In addition, the CBs associated with the 22kV outdoor buses have a history of issues. The extent of the defects appearing relating to mechanical faults is progressively becoming more serious as the age of the assets well beyond their economic life, as described below.

   <u>Email 345GC 22kV CB's</u>

   These CB's have been undergoing a bushing refurbishment program, due to a history of compound leaks from the bushings. The bushing refurbishment program is in response to a known defect. This refurbishment program is designed to prevent bushing failure. There have also been minor defects associated with the CB mechanism, particularly with capacitor bank CB's. This issue has been managed successfully.

   There have been a small number of failures of the main contact pull rod. The maintenance schedule has been modified to remove the class 2 overhaul at 12 years and implement a class 2 overhaul at 6 years to identify any fractured pull rods. Generally, this failure mode is associated with capacitor bank switching and the associated onerous operating duty. It is also suspected that the leaking dashpots might be a contributing factor to the failure of the pull rods. A project to replace the existing Permali wood pull rods in all 345GC cap bank CBs with fibreglass pull rods has been completed. This was following the failure of the existing Permali pull rods in several 345GC capacitor bank CBs across JEN. During the pull rod replacement project, it was further identified that the pull rod guides were worn and unserviceable. When a defective pull rod is identified in any other breaker, pull rods on all three phases will be replaced with fibreglass pull rods and the dashpot serviced.

   New failure modes are emerging as the asset is continuing to age beyond the expected serviceable life. Failure of some existing components can be mitigated by engineering new components, but this process is costly and this does not mitigate the age or age related failure of other components within the CB.

   In September 2015 BD3 22kV FDR CB failed to open when a command was issued from JEN's control room. Upon investigation it was identified that the trip latch assembly presented with a build-up of sticky/tacky residue. The build-up of residue was a consequence of the CB installed outdoors and exposed to the elements. Over a period of time subsequent applications of the lubricant had attracted dirt and dried up, resulting in the trigger and rollers not moving freely.

   The outdoor 345GC CBs are maintenance intensive. Moving the switchgear indoor would alleviate the need for intensive and periodic maintenance.

   <u>Crompton Greaves – 30-SFGP-25A 22 kV CBs</u>

   There have been ongoing issues with these CBs. Gas leaks were found in one CB at Sunbury (**SBY**) and one CB at Yarraville Terminal Station (**YTS**); both of these CBs had all three poles replaced with refurbished poles. In March 2014, while doing corrective maintenance on the AW No.4 22 kV transformer CB the shock absorber was found to have been dislodged. Further investigation found a gas leak from one of the poles of the CB. All three poles were replaced with refurbished poles, and the CB was put back in service. YTS No. 4 transformer 22 kV CB occasionally leaks SF6 gas and is being monitored.

In June 2013 the SBY14 feeder CB had a mechanism failure when it was slow to open on a feeder fault. It was discovered that the mechanism had a build-up of sticky/tacky residue. The build-up of residue was a consequence of the CB installed outdoors and exposed to the elements, as over a period of time repeat applications of the lubricant had attracted dirt and dried up, jamming the mechanism. The CB mechanism was cleaned thoroughly and lubricated with a different lubricant. A plant bulletin was sent out subsequently, highlighting the problem and recommending a different lubricant.

2. **The outdoor 22 kV CBs are non-compliant with current switchgear standards for electrical arc fault containment standards. This presents a health and safety risk to JEN personnel. In the event that the insulation fails, the resulting electrical arc and pressure wave will not be contained within the oil filled CBs, and consequently, the risk employee health and safety is elevated.**

   The outdoor 22kV CBs are not compliant with current safety standards, and the CBs only have oil discharge vents to the switchyard. In the event of a CB fault, the over pressure may cause the metal tank/housing to rupture, releasing gas pressure and hot oil which is potentially a fire and safety 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.

   New switchgear is designed and type tested to AS-62271.200 to provide a safe workplace for personnel and reduce consequential damage.

3. **The switchgear (Email 345GC) is obsolete, and the lack of spares necessary to recover from a catastrophic failure may impact supply reliability to JEN customers. This switchgear is no longer supported by a manufacturer and spare components are no longer available.**

   Spare bushings, and spare CB components are limited and in most cases, non-existent. Repairs have been performed by refurbishing the bushings and getting new components made. This is not a long term solution. CB spare parts are running low. Performing repairs following a catastrophic failure will be difficult and may not be possible with the existing assets.

4. **Outdoor 22 kV transfer bus: There are known defects associated with pin and cap 22 kV insulators which are prone to failure. There have been two serious incidents within other electricity businesses. In one instance a 22 kV 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 22 kV switchgear provides an opportunity to the remove outdoor 22 kV transfer buses to remove the associated safety risk.**

   These insulators consist of a galvanised steel pin cemented into the porcelain and over time as moisture corrodes the pin, the expansion of the rust causes 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.

   If the Transfer buses were to remain in-service, the 22 kV pin and cap insulators will be replaced to mitigate a known safety risk.

   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 suspended one metre from the ground and clear of other structures. The bus remained alive and was discovered by personnel doing ground maintenance.

   In 2013 after operating three phase 22 kV powder filled fuse units, the red phase insulator broke, dropping the conductor towards the operator.

Pin and cap type insulators have generic design deficiencies that can lead to insulator failure in service.

This replacement part of the work is solely driven by health and safety. There is no evidence that would indicate any supply reliability improvements as there is no incidence of bird strikes. Reliability levels would be maintained at current levels.

5. **The 66 kV Bus Tie CB's represents a family of breakers with a history of mechanical failure and catastrophic bushing failures. This CB, 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 LG4C 66 kV CBs manufactured from 1964 in service with one installed at sub CN.

   There were two catastrophic failures of this type of CB at Brooklyn and one at West Melbourne Terminal Stations in the late 1990's and early 2000's and these failures related to the 66 kV bushings as the bushing DLA (Dielectric Loss Angle) had deteriorated to the point of failure.

   These CBs are no longer supported by the manufacturer and consequently, spare components such as 66 kV bushings, turbulators, solenoids and mechanism components are no longer available. The failure of 66 kV bushings is a risk to the safety of field crews. Continued maintenance and testing will not prevent the failure of a bushing as the DLA and PD continues to deteriorate. The cost of engineering new replacement bushings, procurement and installation would be comparable to a new CB installed. Replacement of the bushings alone does not address the mechanical wear and lack of spare parts.

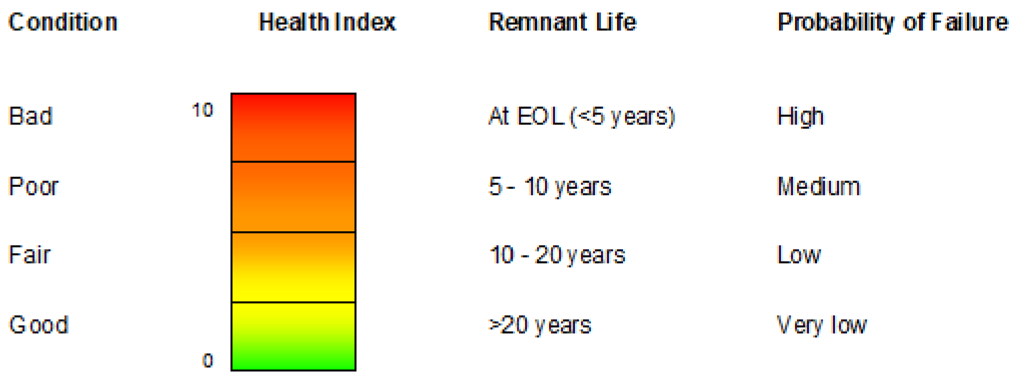
   There has been a defect identified in the mechanism of these CBs involving the retaining of a shaft by a washer that is peened on the end of the shaft. This indicates component failure due to mechanical wear and has resulted in damage to the mechanism. New component, a pin, was designed and manufactured, costing in excess of $5,000 to develop, as original spare parts were not available. An inspection of all of these CBs has been undertaken and a plant defect notice issued. This shows that the CBs are entering a wear out phase and due to lack of spare parts, components are being re-engineered independently outside of the original equipment manufacturer specification which takes time and is costly.

2.2.2 RISK ASSESSMENT

Condition Based Risk Management (**CBRM**) modelling has been introduced for switchgear assets and is used 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 ZSS related assets is in document 'JEN CBRM Report – ZSS 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.

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 the probability of failure. The concept is illustrated schematically below.



For the 22 kV CBs, the CBRM modelling results for the current health index (Y0) and the replacement year health index (2023, Y4) are presented in Table 2-7 below.

Table 2-7: CN 22kV CBs Health Index Results

Designation	Make	Type	HI Y0	HI Y4
1-2 22KV BUS TIE CB	EMAIL	345GC	8.25	9.53
2-3 22KV BUS TIE CB	SIEMENS	3AF 2732-4Z	2.15	2.63
FDR CN 1 CB	SIEMENS	3AF 2732-4Z	3.11	3.86
FDR CN 10 CB	SIEMENS	3AF 2742-4Z	2.11	2.63
FDR CN 11 CB	CROMPTON GREAVES	30-SFGP 25A	3.82	5.33
FDR CN 2 CB	EMAIL	345GC	7.98	9.27
FDR CN 3 CB	EMAIL	345GC	7.98	9.19
FDR CN 4 CB	EMAIL	345GC	7.98	9.19
FDR CN 5 CB	EMAIL	345GC	7.98	9.19
FDR CN 6 CB	EMAIL	345GC	8.25	9.53
FDR CN 7 CB	EMAIL	345GC	7.98	9.19
FDR CN 8 CB	EMAIL	345GC	7.98	9.19
FDR CN 9 CB	SIEMENS	3AF 2742-4	2.36	2.94
NO.1 CAP BANK CB	EMAIL	345GC	7.98	9.27
NO.1 TRANS 22KV CB	EMAIL	345GC	7.98	9.19
NO.2 CAP BANK CB	EMAIL	345GC	7.98	9.19
NO.2 TRANS 22KV CB	EMAIL	345GC	8.25	9.53
NO.3 CAP BANK CB	SIEMENS	3AF 2732-4Z	3.38	4.19
NO.3 TRANS 22KV CB	SIEMENS	3AF 2732-4	2.32	2.86

The figures in the table above indicate that the 345GC CBs are in a bad condition currently, and will be in a severely deteriorated condition in 2023 if the replacement isn't undertaken. This modelling result is consistent with the issues identified.

For the 66 kV CBs, the CBRM modelling results for the current health index (Y0) and the replacement year health index (2023, Y4) are presented in Table 2-8 below.

Table 2-8: CN 66kV CBs Health Index Results

Designation	Make	Type	HI Y0	HI Y4
1-2 66KV BUS TIE CB	AEI	LG4C/66G	6.60	7.53
2-3 66KV BUS TIE CB	ASEA	HLC 72.5/2000	2.66	3.36
SUB CS FDR 66KV CB	ABB	EDF SK 1-1	1.30	1.59

For the 66 kV CB, the CBRM modelling indicates that the CS 1-2 66 kV bus tie CB has a current health index (Y0) result of 6.60. This indicates that the CB is in poor condition. In Year 4 (2023, Y4), the CB result becomes 7.53. This modelling result is consistent with the issues identified.

For the 22kV transfer buses and associated isolators, the CBRM modelling indicates a current health index result of 9.45. In Year 4 (2023), the health index results will go beyond 10, indicating a severely deteriorated state requiring imminent replacement.

2.2.2.1 CN 22kV Outdoor CB Failure Risk

Failure Modes

The failure modes of the CN 22kV outdoor CBs can include:

- Bushing insulation failure;
- Mechanical failure (failure to open or close);
- Insulation medium degradation;
- Lightning and other line surges;
- Inadequate maintenance; and
- Design/manufacturing errors.

Due to the deteriorated condition of the CBs, insulation failure is likely to occur.

Likelihood of Failure

The probability of a 22kV CB failure can only be estimated from limited historical data, engineering experience and condition test reports. From Table 2-2: CN 345GC Switchgear Defect History, the failure modes have been summarised below:

- Bushing defect;
- Failed to operate;
- CB slow trip; and
- Oil leaks.

There are 46 Email 22kV outdoor CBs installed at CN, AW and BD and 70 fault records in 10 years. The major issue is the leaking of the compound pitch from the 22kV bushings and its impact on personnel safety and the lack of spares to recover from a catastrophic failure. The condition of the Email 345GC CBs will continue to degrade over time.

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 cyclical due to temperature variations or linear increase over the same period, ultimately resulting in failure. CBRM predicts one 22kV outdoor CB could fail and be beyond repair due to poor condition in the next 5 years, The probability of the CN 22kV Email CBs failing is taken to be 20%. This failure rate is likely to increase with age.

Consequence of Failure

The consequence of a catastrophic failure of the 22kV CB at CN would likely be the interruption of supply to 2/3 of the station load (for the failure of the 2-3 22kV bus-tie CB, this is the worst case). The switchgear contains bulk oil volume for insulation and to interrupt current. The scenario considered is the loss of two 22kV outdoor buses resulting from the failure of the 2-3 22kV bus-tie outdoor 22kV CB. It is likely that 2/3 of the station customers (on average) will be off supply for 1 hour until the operational personnel get to the station and isolate the CB and reinstate the No.1 and No.2 22kV transformer CBs to restore supply.

Network Performance

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

1h x 60(mins) x \$0.90/min + 24,000 x 2/3 (Customers) x \$56.56/Cust = \$905k

Note: 24,000 are the number of customers supplied out of CN ZSS.

CAPEX

The capital expenditure associated with the failure of a single 22 kV outdoor CB is estimated to be \$250k. 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 is estimated to be less than \$100k per event. 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 worst case cost of risk for a bus 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

= (\$905k + \$250k + \$100k) x 20%

= \$251k p.a.

2.2.2.2 CN 66kV CB Failure Risk

Failure Modes

The failure modes of a CB can include:

- Bushing insulation failure;
- Mechanical failure (failure to open or close);

- Insulation medium degradation;
- Lightning and other line surges;
- Inadequate maintenance; and
- 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 the 1-2 66kV bus tie CB failure at CN 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 1990's and early 2000's and these failures related to bushings.

There have been numerous other failures of this type of CB (both on the JEN network and other distribution businesses in Victoria), and these include:

- 1984 – AW – Failed to close;
- 1983 – 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. However, not all failures can be picked up during maintenance. Refer to section 2.2.1 - 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 there are nine of this type of CB in service on the JEN, the probability of the CN 66 kV CB failing is taken to be 1/3/9 = 3.7%.

In consideration of a catastrophic bushing failure of 3 in 15 years and a population of 9 CBs, the probability of the CN 66kV CB failure scenario is taken to be 3/15/9 = 2.22%.

Consequence of Failure

The consequence of a catastrophic failure of the 1-2 66 kV bus tie CB at CN would likely be an interruption of supply to 2/3 of the station. It is likely that 2/3 of 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 3 transformers at CN would be on a single 66 kV 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:

1(hr) x 60(mins) x $0.90/min (SAIFI) + 24,000 x 2/3 (Customers) x $56.56/Cust (SAIDI) = $905k

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 $100k per event. 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 worst case 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

= ($905k + $350k + $100k) x 2.22%

= $30k p.a.

2.2.2.3 CN Outdoor 22 kV Transfer Bus Failure Risk

Failure Modes

The failure modes of a 22 kV bus can include:

- Insulator electrical failure;
- Mechanical failure;
- Lightning and other line surges;
- Inadequate maintenance; and
- 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 failure of an outdoor 22 kV bus section at CN is low. For risk/cost calculations, a 1% probability is used.

Consequence of Failure

The consequence of a failure of an outdoor 22 kV transfer bus section at CN would likely be an 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 22 kV underslung isolators on a feeder. Falling porcelain/equipment and/or contact with live 22 kV conductors could cause permanent disability or even death to a staff member.

Network Performance

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

4(hrs) x 60(mins) x $0.90/min + 1500 (Customers) x $56.56/Cust = $85k.

CAPEX

The capital expenditure associated with a single permanent failure is estimated to be $4k. This represents the equipment replacement costs for one 22 kV underslung isolator. There are 22 outdoor underslung isolators in question and the estimated total cost to replace is $88k.

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. The cost of a fatality is $1.2M.

Total Cost of Risk

The worst case 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

= ($85k + $88k + $5k) x 1%

= $1.78k p.a.

The annualised cost of a single fatality using a probability of 1% is $12,000.

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.

2.3 PROJECT OBJECTIVES AND ASSESSMENT CRITERIA

Objective

The objective of the project is to determine the most appropriate strategy for the nominated assets to maintain customer supply reliability at CN, given their current condition. This strategy must be consistent with other JEN

Strategies and plans and must comply with associated regulatory requirements including the National Electricity Rules (in particular clause 6.5.7), the Victorian Electricity Distribution Code and Environmental Protection regulation.

Seven options will be explored in the Options Analysis in Section 3 of this document to identify the best possible option. The options will be benchmarked against the risks to ensure the health, safety and reliability issues are addressed. Fundamentally risk, cost and value will be the primary drivers however, the best value option, not the cheapest will be recommended.

Regulatory Requirements

The section of the National Electricity Rules (Version 124) relevant to this project is:

Section 6.5.7 – Forecast Capital Expenditure

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 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.*

The sections of the Electricity Distribution Code (Version 9A – August 2018) relevant to this project are:

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

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, JEN seeks to comply with these regulatory obligations through the development and implementation of the Electricity Primary Plant Asset Class Strategy.

Assessment Criteria

The assessment criteria by which projects will be assessed and the extent to which each of the identified options addresses the Five asset condition issues are described in Section 2.2.

2.4 CONSISTENCY WITH JEN STRATEGY AND PLANS

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

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

JEN seeks to ensure that the 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 (Asset Management Plan) and annual planning reports.

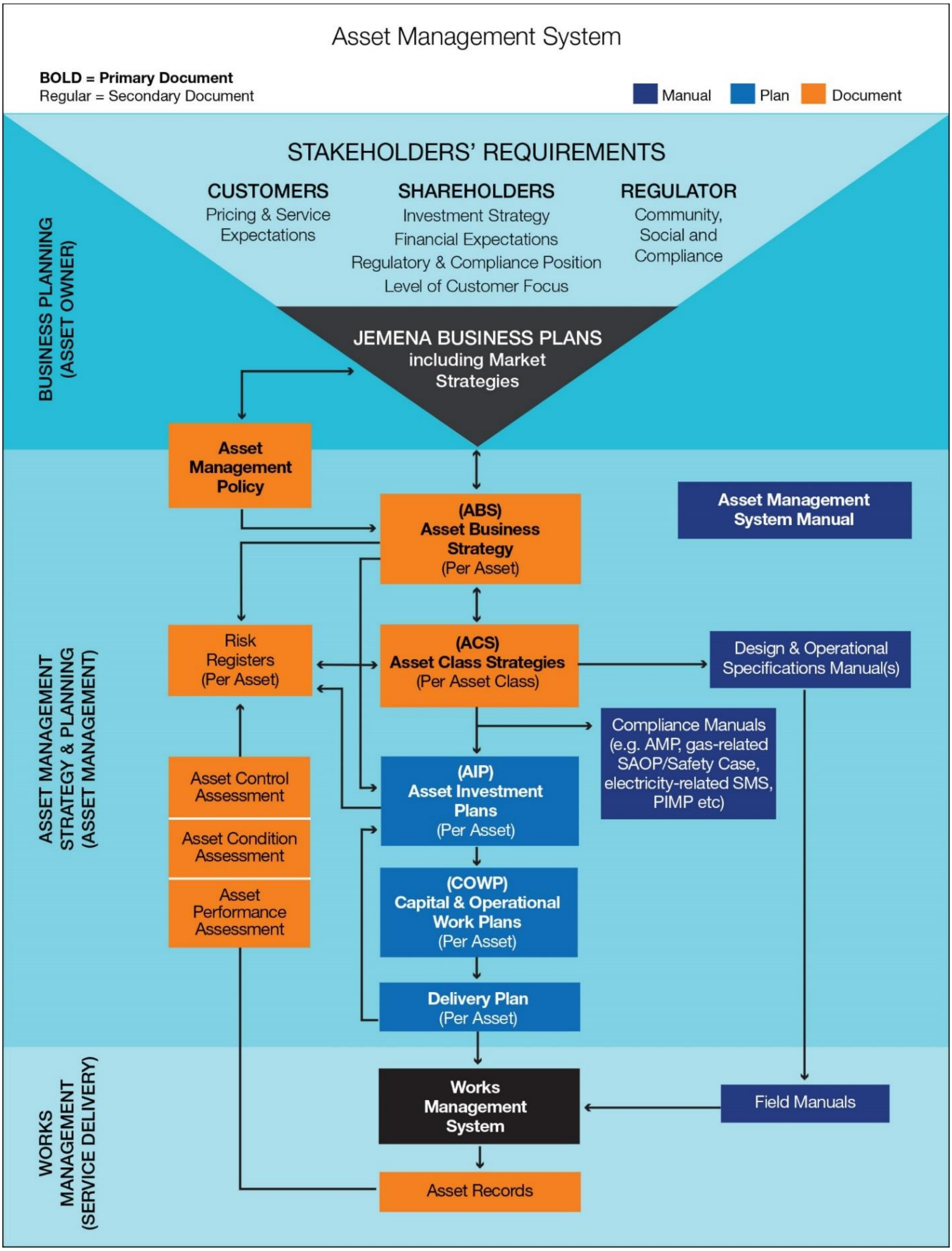
JEN must comply with regulatory obligations; these are incorporated into the development and implementation of its ZSS Primary Plant Asset Class Strategy (ELE AM PL 0061). The Asset Class Strategy creates a line of sight between the JEN Business Plan and the Asset Management Plan.

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 and will increase supply security and maintain reliability. By completing this project, JEN can reduce its exposure to the possibility of litigation by authorities due to an injury or environmental incident.

Figure 2–5 outlines the JEN Asset Management System and where the Asset Management Plan (**AMP**) is positioned within it. The AMP covers the creation, maintenance and disposal of assets including investment planned to augment network capacity to meet increasing demand and to replace degraded assets to maintain the reliability of supply to meet JEN Business Plan requirements.

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

Figure 2–5: The JEN Asset Management System



3. CREDIBLE OPTIONS

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

3.1 IDENTIFYING CREDIBLE OPTIONS

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

1. Do Nothing
2. Increased Maintenance and Monitoring
3. 22 kV and 66 kV Switchgear Refurbishment
4. Transfer Load
5. Replace 22kV (indoor) and 66kV CBs
6. Replace 22kV (outdoor) and 66kV CBs
4. Non-network solutions

3.2 DEVELOPING CREDIBLE OPTIONS COSTS & BENEFITS

The following section discusses the feasibility, practicality, costs and benefits associated with each of the credible options to identify which of these to be taken forward for further evaluation.

Note that all expected option costs include overheads.

The option of a non-network solution (e.g. demand management and/or embedded generation) is not an alternative for removing the asset condition risk at the ZSS. The asset condition risk would remain until the assets are either replaced or decommissioned.

A comparison of the seven options listed above and the issues they address is shown in Table 3-1.

Table 3-1: Options Analysis

Condition Issue	**Option1** Do Nothing	**Option2** Increased Maint. & Monitoring	**Option 3** Switchgear Refurb	**Option 4** Load Transfer	**Option 5** Replace 22kV CBs (indoor) & 66kV CBs	**Option 6** Replace 22kV CBs (outdoor) & 66kV CBs	**Option 7** Non-network Solutions
Issue 1 Switchgear Condition	○	○	◑	●	●	●	●

Condition Issue	**Option1** Do Nothing	**Option2** Increased Maint. & Monitoring	**Option 3** Switchgear Refurb	**Option 4** Load Transfer	**Option 5** Replace 22kV CBs (indoor) & 66kV CBs	**Option 6** Replace 22kV CBs (outdoor) & 66kV CBs	**Option 7** Non-network Solutions
Issue 2 Non arc fault Containment	○	○	○	●	●	○	●
Issue 3 Lack of Spare Parts	○	○	○	●	●	●	●
Issue 4 22 kV Insulators	○	○	○	●	●	●	●
Issue 5 66 kV CBs	○	○	◑	●	●	●	●
Technically & Financially Viable	○	○	○	○	●	○	○

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

Each of these options are discussed in detail below.

3.2.1 OPTION 1 - DO NOTHING

The do nothing option assumes a business as usual scenario. The current maintenance activities would continue including inspections, condition monitoring, preventive work and repair of defects. Maintenance will not improve the insulation condition of any asset/s. 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 condition is at imminent risk of catastrophic failure and it would then be taken out of service, thus placing the supply reliability at increased risk.

The option does not address any of the five condition issues described in Section 2.2. In particular, the 22kV switchgear condition (Issue 1) would not be resolved, and the probability of failure of the CBs would remain.

The CBs insulation is in poor condition, and the degradation that has occurred is irreversible. For this reason, Option 1 is not considered. This option is not credible as the point of failure cannot be predicted even though condition testing is implemented, the frequency of future tests may not target the point of failure in time and the CBs will fail catastrophically in service.

Given the criticality of this issue, it is not recommended to pursue any option that does not address it.

3.2.2 OPTION 2 - INCREASED MAINTENANCE AND MONITORING

Under this option, the CN CBs would be more closely monitored, and the frequency and range of condition testing would be increased. The ultimate failure of the CBs cannot be prevented if the CBs 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 five issues described in Section 2.2. In particular, the asset condition of the 22kV and 66kV CBs, including the outdoor 22kV isolators would not be resolved, and the risk of failure of these assets and impact on personnel safety would remain.

Given the criticality of this issue, it is not recommended to pursue any option that does not address it.

3.2.3 OPTION 3 – CB REFURBISHMENT

22kV CB refurbishment is not possible as the replacement of individual parts or bushings is no longer supported by the manufacturer, and any such action if possible would be cost prohibitive. This option would only address the bushing pitch leak and oil leaks, and the switchgear performance, safety and reliability would not change from the original design in 1967 which does not conform to current Australian safety standards for arc fault containment given that the 345GC CBs are bulk oil. Research and development costs, type testing, design work, installation and commissioning could be double the project cost to replace the switchboard.

The refurbishment of switchgear which is 51 years old, is not recommended, and it would not be technically feasible. Spare parts are not available and the switchgear is beyond 51 years old as well as being non-compliant to current safety standards (AS-62271.200), in particular, the ARC fault containment. It is for these reasons that this option is not considered.

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

3.2.4 OPTION 4 - TRANSFER LOAD

The transfer load option involves the transfer of all load from CN and the temporary or permanent retirement of the ZSS. If all load was transferred away from CN, 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.

This option would solve all five of the current condition issues at CN.

Although approximately 1/3 of the load can be transferred to adjacent feeders without any capital investment, this would be restrictive on any further network operations. There would be no further contingencies available.

In the event of the failure of a 22kV CB or the 1-2 66kV bus tie CB at CN, 1/3 of the station load (22kV CB failure) or 2/3 of the station load (66kV CB failure), would be lost for an hour while transfer and switching take place to isolate the plant and restore the lost load. All of the station load would be restored in this time.

The current maximum demand at CN is 65.7 MW. This would require two additional 33 MVA transformers, 22kV switchgear, new feeders, and an extended control building with all associated protection and control equipment for a new ZSS.

Establishment of a greenfield ZSS is estimated to be $16M and this is based on the approved business case for ZSS YVE (including overheads and escalation to 2018). YVE was commissioned in 2014. This estimate is conservative due to the costs associated with establishing sub-transmission circuits in well-established urban areas, and the cost of acquiring land, however, the figure will be used as a basis of comparison.

Augmenting an existing ZSS or establishment of a new ZSS to replace CN would not be a prudent method of addressing the existing asset condition at CN. The cost of this establishment would be far in excess of the cost to replace the switchgear at CN.

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

3.2.5 OPTION 5 - REPLACE 22KV CBS (INDOOR) AND 66KV CBS

This option involves replacing the existing outdoor 22kV CBs with new modern indoor switchgear and installing them to current standards, including the retirement of the outdoor 22kV transfer buses. The new indoor metalclad switchgear would conform to current safety standards, including arc fault containment. This option also involves the replacement of the 1-2 and 2-3 66kV bus-tie CBs with modern outdoor dead tank CBs. To mitigate against loss of one 66/22 kV transformer for a 66kV line fault, a new 66kV line CB (CN-TTS) at an incremental cost to this project of $0.3M ($2019 Real) will also be installed, delivering additional net benefit to customers.

This option would address all the condition issues identified in Section 2.2 and will maintain safety, reliability and security of customer supply.

The total cost of this option is estimated to be $7.765M (real $2019), and the project would commence in 2022. The switchgear will then be over 55 years old.

3.2.6 OPTION 6 - REPLACE 22KV CBS (OUTDOOR) AND 66KV CBS

This option involves replacing the existing outdoor 22kV CBs with new outdoor 22kV CBs. The outdoor 22kV transfer buses would remain in service. The new outdoor 22kV CBs would not be arc fault contained. This option also involves the replacement of the 1-2 and 2-3 66kV bus-tie CBs with modern outdoor dead tank CBs.

This option would not address all the condition issues identified in Section 2.2, and therefore, this option is not considered as a credible option.

3.2.7 OPTION 7 – NON-NETWORK SOLUTIONS

Non-network solutions are alternatives to network augmentation which address a potential shortfall in electricity supply in a region. Such options are considered whenever we face an investment need; they offer the opportunity to defer or avoid capital costs. These solutions are typically better tailored to local needs and enable us to adapt quickly to changing operating conditions.

In the context of the CN Switchgear Replacement project, there is no potential for non-network options to defer capital investment as the capital investment is required to upgrade ageing and deteriorated assets and not to address the shortfall in electricity supply.

The following non-network options were considered:

- Embedded generation (a generating unit connected to the distribution network), and
- Energy storage (such as batteries which can be charged overnight during the off-peak period enabling electricity to be stored and discharged during peak times).

Load curtailment a reduction in consumption during a defined period. This includes both ceasing to (in part or full) to consume electricity as well as shifting consumption to outside the critical period.

4. OPTION EVALUATION

This section discusses the economic analysis that was done 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	Option 4	Option 5
Total Expected costs	0	16,000	7,765
Total Expected market benefits	-	44,800	44,800
Net market benefits	-	28,800	37,305
Option ranking	3	2	1

On the basis of above economic analysis, Option 5 is the preferred option.

5. PROJECT TIMING

The 22kV 345GC CBs suffer from several issues. The major issue is the 345GC CBs pitch filled bushing defects. The bushings have been found to be leaking pitch and a program was initiated to refurbish all bushings on the 345GC CBs on the JEN, however, even after the refurbishment, there is no guarantee that the bushings will remain defect-free and won't fail when their insulation is compromised. In recent years the main contact pull rods have also experienced failures. These pull rods were made from Permali wood, which is no longer available. These pull rods have been replaced with fibreglass pull rods. Refer to section 2.2.1 - Asset Condition for more details on the CBs.

Catastrophic insulation failure can be triggered by lightning, and other line surges anytime. Insulation degradation at normal service voltage can be 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 outdoor CB could fail beyond repair due to poor condition in the next 5 years. This failure rate is likely to increase with age.

There are known defects associated with pin and cap 22 kV insulators which are prone to failure. There have been two serious incidents within other electricity businesses. In one instance a 22 kV 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 22 kV switchgear provides an opportunity to the remove outdoor 22 kV transfer buses to remove the associated safety risk.

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

The CBRM modelling indicates that the CN ZSS 22 kV Email CBs have a current average health index result of 8.04. This indicates that the CBs are in a severely deteriorated condition. This modelling result is also consistent with the issues identified.

In Year 4 (2023), the average health index result becomes 9.29.

For the 22 kV transfer buses and associated isolators, the CBRM modelling indicates a current health index result of 9.45. In Year 4 (2023), the health index results average above 11.5.

For the 66 kV CBs, the CBRM modelling indicates that the CN 1-2 66 kV bus tie CB has a current health index result of 6.6. This indicates that the CB is in poor condition. This modelling result is also consistent with the issues identified.

In Year 4 (2023), the CB result becomes 7.53.

Consequently, this project is scheduled to commence in 2022 and be completed in 2023.

6. REGULATORY TREATMENT

The purpose of this project is to maintain rather than improve network performance through the timely replacement of the aged plant that is in poor condition. Maintaining network performance will be achieved by avoiding the impact of a failure of one or more items of plant at CN.

Maintaining network performance is consistent with the objectives of the Electricity Primary Plant Asset Class Strategy:

- Achieve a 50-year life; and
- Minimise supply interruptions to customers.

If the asset remains in service beyond its nominal lifespan, its condition will deteriorate and impact employee safety, and the reliability of customer supplies will decrease.

7. RECOMMENDATION

This business case proposes a total investment of $7.765M (total project cost, real $2019) and requires Managing Director's (Band B) approval under the SGSPAA DFA Manual, Annex 3.

It is recommended that Option 5 be adopted and the outdoor 22 kV CBs and the two 66kV bus tie CBs be replaced with new modern equivalents, a new 66kV line CB installed and a new building installed to current standards. The new 22kV switchboard will be fully rated, arc fault contained, utilising vacuum CBs.

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

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

The total cost of this option is estimated to be of $7.765M (total project cost, real $2019) and the project would commence in 2022. The switchgear will then be over 55 years old and beyond its design life.

Appendix A
Project Scope and Delivery Information

Jemena

A1. HIGH LEVEL SCOPE

PRIMARY ELECTRICAL REQUIREMENTS

Primary works for this project shall be carried out to meet the requirements of the relevant standards unless otherwise stated.

TRANSFORMERS

The No.1, No.2 and No.3 transformers require new 66kV CT's to be installed. The existing (x3) CT's per phase are installed within the 66kV turrets. The No.1 & 2 transformer 66kV neutral bushings will be replaced with new ABB GSA type. New turrets, CT's (x4) per phase and 66kV bushings will be fitted to the No.1, No.2 and No.3 transformers. The feasibility of this work will need to be verified.

Replace No.2 transformer oil seal between the OLTC diverter switch, selector switch and drive mechanism.

Transformer oil bunds are to be cleaned, transformer oil leaks rectified and any paint missing on transformers to be touched up.

66KV EQUIPMENT

The erection and connection of 66kV equipment:

- Installation of a new dead tank 1-2 and 2-3 66kV bus tie CBs, three single phase VT’s on the sub CS FDR.

Replacement of 66kV hardware, including:

- Disconnectors/earth switches.
- The TTS FDR disconnect switch will be fitted with an MOD drive mechanism to mitigate risk to customer supplies while the 22kV bus is being replaced. The MOD will need to have local and remote control functionality from the Collins street control room to restore the No.3 transformer following a sustained fault on a 66kV Feeder.
- MOD’s are also needed for No.1, 2 and 3 Transformer 66kV disconnector switches and SUB CS FDR, to satisfy the requirement of a Smart Substation.
- Install 66kV bus earth switches.
- New spherical earthing receptacles as required to replace the cone earths.
- Convert the SUB CS FDR CB controls from 240V DC to 110V DC.

22KV INDOOR EQUIPMENT

No.1, No.2 and No.3 22kV outdoor switchgear is to be replaced with a new indoor 22kV metal enclosed, fully arc contained switchboard.

A total of 22 CBs with associated VT's, earth switch and joggle compartments are required to complete the No.1, No.2 and No.3 22kV buses. Refer to the Single Line Diagram, in the Appendices.

The new 22kV switchboard will consist of:

- Three off 22kV 1250A buses.
- Three 3 phase five limb (or 3 x 1 phase per bus) star connected transformer VT with a single secondary winding, for each bus.
- Two 22kV bus joggles.
- Three 22kV transformer CBs of 1250A rating.
- Two 22kV bus tie CBs of 1250A rating.
- Twelve 22kV feeder CBs of 630A rating.
- Three 22kV capacitor bank panels with integral earth switches. Note the existing cap banks will be rated up to 12MVAr each in the future.

  To calculate the rating of capacitor bank CBs or the step switch CB, the ultimate arrangement for reactive support as per the System Design Sheet needs to be considered. The CB manufacturer is to be consulted to determine the capacitor bank/step switch rating in consideration of Harmonics, voltage tolerance and back-to-back switching. Further information can be obtained from AS 62271.100 and IEC 56. JEN prefers type Class C2 CBs for capacitor bank switching as per Clause 3.4.115 of AS 62271.100, however pricing shall also be submitted to Services & Projects for type Class C3.2 CBs. Note: The Capacitor Banks will be operating with floating neutrals.
- 22kV panels to be sequenced as shown on the Single Line Diagram (refer Appendix A).
- One 22kV spare feeder CB.
- One 22kV spare transformer CB.
- Spare 22kV bus and feeder CT's and VT's.
- The CBs shall consist of modern vacuum type interrupters.
- Humidistats used to control the heater operation shall be separated from any adjacent equipment.

CABLES

Installation and termination of the No.1, No.2 and No.3 transformer 22kV cables (minimum of 2x 1/c 630mm^2 Cu XLPE per phase to their respective CBs to achieve 1250A minimum cyclic rating).

The works will also include:

- Cutting over the existing feeders, transformer cables and capacitor banks to the new switchboard.
- Installation and termination of HV and LV power cables.
- Distribution feeders shall be relabelled in accordance with the nomenclature convention for ZSS.

22KV CAPACITOR BANKS AND EQUIPMENT IN GENERAL

- No.1, 2 and 3 capacitor banks shall have the neutral solid connection removed. The Cap Bank neutral points shall be left to float and a Cap Bank neutral earth switches installed.
- Remove and dispose of the old concrete plinth around the No.1 capacitor bank.
- Install a new No.3 capacitor bank step switch to replace the original faulted unit.
- Replace No.1, 2 and 3 transformer 22kV neutral direct ground isolators.
- Replace No.1, 2 and 3 transformer 22kV NER isolators.

EARTHING

Augmentation of the existing earthing:

- CMEN bonding of feeder cable screens in accordance with standards.
- Upgrade 66kV and 22kV earthing receptacles and station portable earths.
- Spherical fixed points made of copper aluminium bronze shall be installed to replace standard SECV earthing receptacles. The old earths are to be retained by the HV Operators team, to be assessed and reused at appropriate ZSS in accordance with equipment fault ratings.

STATION SUPPLY

Two 22kV/415V 100kVA pad mount station service transformers connected to:

- No.1 22kV bus.

  No.3 22kV bus.

A2. SINGLE LINE DIAGRAM