Jemena Electricity Networks (Vic) Ltd

Replace Broadmeadows (BD) Zone Substation Transformer

2021 and 2022 Business Case

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Replace Broadmeadows (BD) Zone Substation Transformer

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

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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 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 No.1 and No.2 66/22 kV 20/33 MVA transformers at Zone Substation Broadmeadows (BD) are at a high risk of failure due to their poor condition;
- To manage the risk of damage to key assets within BD Zone Substation due to condition-related failure this business case recommends replacing the existing No.2 66/22kV transformer with standard 20/33 MVA unit and make the existing No.1 66/22kV transformer a hot standby, and
- The project will be completed in 2022 at a cost of $4.1M (total project cost, real $2019).

1.1 BUSINESS NEED

Broadmeadows (**BD**) zone substation, consisting of four power transformers, operates at 66/22kV and has fourteen 22kV feeders which supply approximately 13,000 customers. The No.1 and No.2 20/30MVA Wilson Transformer Company (**WTC**) power transformers are 45 and 50 years old respectively.

Tests undertaken on zone substation BD transformers and Condition Based Risk Modelling (CBRM) have identified significantly deteriorated assets which has triggered replacement prioritisation. As the JEN transformer fleet condition has been assessed, the planned and controlled replacement can be cost effectively managed prior to catastrophic failure occurring.

Three current issues associated with the BD transformers have been identified:

1. **Intrusive insulation paper samples taken from the winding leads located within the top of the main tanks of the No.1 and No.2 transformers in 2013 by WTC and TJ H2b had a resultant DP (Degree of Polymerisation) of 292 and 253 respectively.**

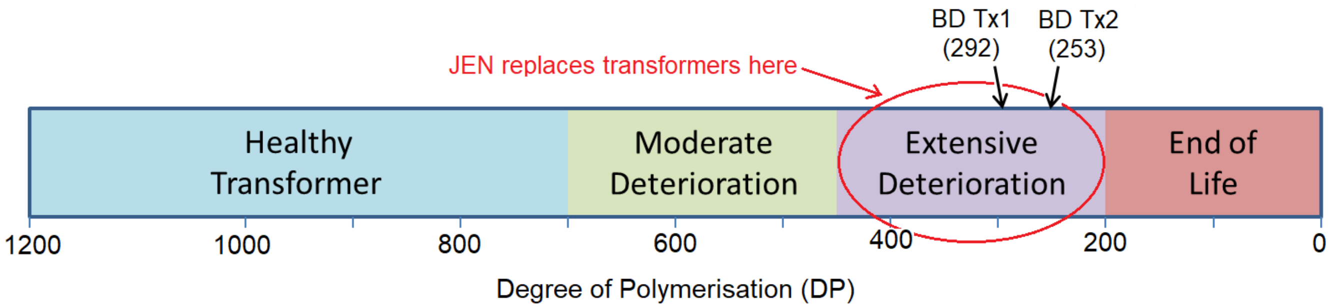
   The mechanical condition of the transformer paper insulation will usually determine when a transformer is at end of life as this degradation is not reversible and when the condition has reached a poor state, there is no economic corrective action to maintain the performance of the transformer. It is at this time that major refurbishment (if practicable and economic) or replacement of the transformer will be required.

   Currently the accepted method of life assessment for transformers is Degree of Polymerisation (**DP**) which quantifies transformer paper condition. While the determination of “end of life” is not absolute, a DP value of between 200 and 450 signifies that a transformer’s insulation has experienced extensive deterioration and should be scheduled for replacement before failure occurs. A DP value less than 200 signifies that a transformer has reached end of life and is unreliable.

   Intrusive insulation paper samples taken from the winding leads located within the top of the main tanks of the No.1 and No.2 transformers at zone sub BD in 2013 by WTC and TJ H2b had a resultant DP (Degree of Polymerisation) of 292 and 253 respectively.

   The paper samples from the No.1 and No.2 transformers’ confirm that the mechanical strength of the cellulose is extensively deteriorated as shown below.

Figure 1–1: Degree of Polymerisation Index



The paper samples at BD were taken from leads located within the top of the main tank, but DP values will be significantly lower within the transformer windings. The degradation of paper of a small localised area of insulation in the vicinity of the hottest spot within the transformer winding can be just as terminal as the degradation of the entire winding insulation. The DP of the No.1 and No.2 transformers at BD can be as low as 150 within the hottest spot of the winding which is well below industry standard. Refer to Section 2.2.1 for more information on the DP variance along a transformer winding.

The paper samples from the two transformers confirm the mechanical strength of the cellulose has deteriorated and is placing the transformers at risk of failure. A close in feeder fault will impose mechanical stress on the winding and may tear the paper and reduce the electrical insulation, resulting in a catastrophic transformer failure. This is the critical issue.

2. **Intrusive insulation paper samples taken from the winding leads of the No.1 and No.2 transformers in 2013 by WTC and TJ H2b determined moisture content of paper sample at time of testing at 20°C to be 6.3% and 5.4% respectively.**

   A transformer's moisture content is a significant indicator of the transformer's condition and a major contributor to the rate of ageing of the paper insulation. A water content of 2.2% in insulation is classed as moderately wet[1]. Moisture in insulation deteriorates the dielectric withstand strength, increases the rate of cellulose ageing, and in the case of excessive temperatures generates gas bubbles. That is why moisture content in insulation of power transformers should be monitored.

   The No.1 and No.2 transformers at BD have moisture contents of 6.3% and 5.4% respectively. This indicates that the paper insulation is extremely wet and the condition of the paper is severely deteriorated. This is also a critical issue.

3. **The transformers have a history of oil leaks on the main tank and radiators.**

   This is not an issue that is driving the replacement of the transformers however it does require elevated levels of operating expenditure to manage. The oil leaks make the transformers maintenance intensive.

   By replacing the transformers the maintenance costs could be minimized and used to offset the cost to replace the transformer/s.

The following options to address these issues have been considered.

1. Do nothing
2. Increased maintenance & monitoring
3. Transformer refurbishment

[1] Limits for water content are defined in the IEC 60422 standard.

4. Transformer re-wind
5. Transfer load
6. Replace one transformer
7. Replace both transformers
8. Non-network solutions

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 zone substation.

A comparison of the eight options listed above and the issues they address is shown in Table OV – 1-1 below.

Table OV–1-1: Options Analysis

Issues	Option 1 Do Nothing	Option 2 Increased Maint. & Monit.	Option 3 Transformer Refurbishment	Option 4 Transformer Rewind	Option 5 Permanent Load Transfer	Option 6 Replace One Transformer	Option 6 Replace Two Transformers	Option 7 Non-Network Solution
Issue 1 Insulation Paper	○	○	○	●	●	●	●	○
Issue 2 Insulation Paper Moisture	○	○	○	●	●	●	●	○
Issue 3 Transformer Oil Leaks	○	●	●	●	●	●	●	○
Issue 4 Safety Risk - Catastrophic Failure	○	◑	●	●	●	●	●	○
Issue 5 Customer Reliability	○	◑	●	●	●	●	●	○
Technically Viable	○	○	○	○	○	●	●	○

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

1.2 RECOMMENDATION

Option 6 is recommended for a total cost of $4.1M (total project cost, real $2019) and involves replacing the existing No.2 WTC 66/22kV 20/33MVA transformer with a higher capacity 20/33MVA transformer and making the existing No.1 WTC 66/22kV 20/33MVA transformer a hot standby. The replacement transformer will have a higher thermal rating at minimal extra cost. This option is considered prudent, and provides maximum net market benefit, in addition to addressing all the condition issues identified in Section 2.2 as it mitigates the risk to network performance and is the preferred option.

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 BD 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.

Six 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 risk assessment from Appendix D 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.

1.4 FINANCIAL INFORMATION

1.4.1 FORECAST EXPENDITURE AND BUDGET SUMMARY

This business case proposes a total investment of $4.1M (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 2022.

The project's expenditure is forecast to occur in 2021 and 2022. The project will be managed within the JEN program of works as required and will be adjusted accordingly to ensure the overall JEN program budget is not exceeded in these three financial years.

Table 1-2 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

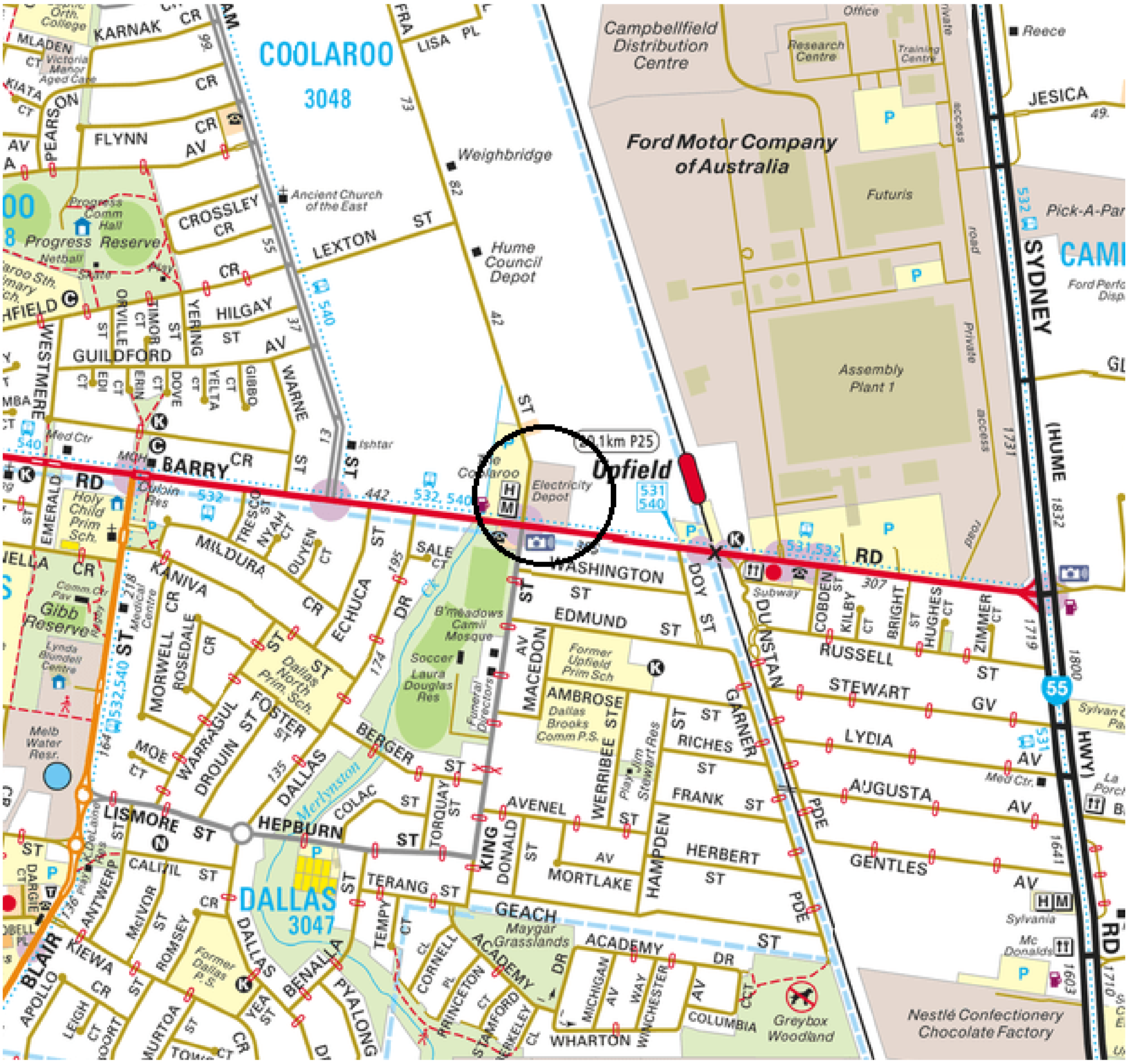
Business Case Spend	Total ($'000s, $2019)
CAPEX	3,624
Overhead Recovery	544
Total Business Case Value	**4,141**

2. BACKGROUND

The purpose of this document is to set out the business case for Broadmeadows Zone Substation (BD) transformer replacement project. This business case examines the regulatory treatment in the JEN building block proposal and also confirms that the business case aligns with JEN's Electricity Primary Plant Asset Class Strategy. See Appendix A – ELE AM PL 0061 Electricity Primary Plant Asset Class Strategy.

BD was commissioned in 1965 and is located to the north of the Melbourne CBD on the corner of Barry Road and Maffra Street, Coolaroo (Melway Ref: 7 C3) as shown in Table 2-1. It supplies approximately 13000 customers in the Broadmeadows, Meadow Heights, Jacana and Campbellfield areas. The customer split based on customer numbers is 82.2% residential, 17.2% commercial and 0.6% industrial. The split based on energy consumption is 36.1% residential, 22.1% commercial and 41.8% industrial.

Figure 2–1: Location of Zone Substation BD (Broadmeadows)



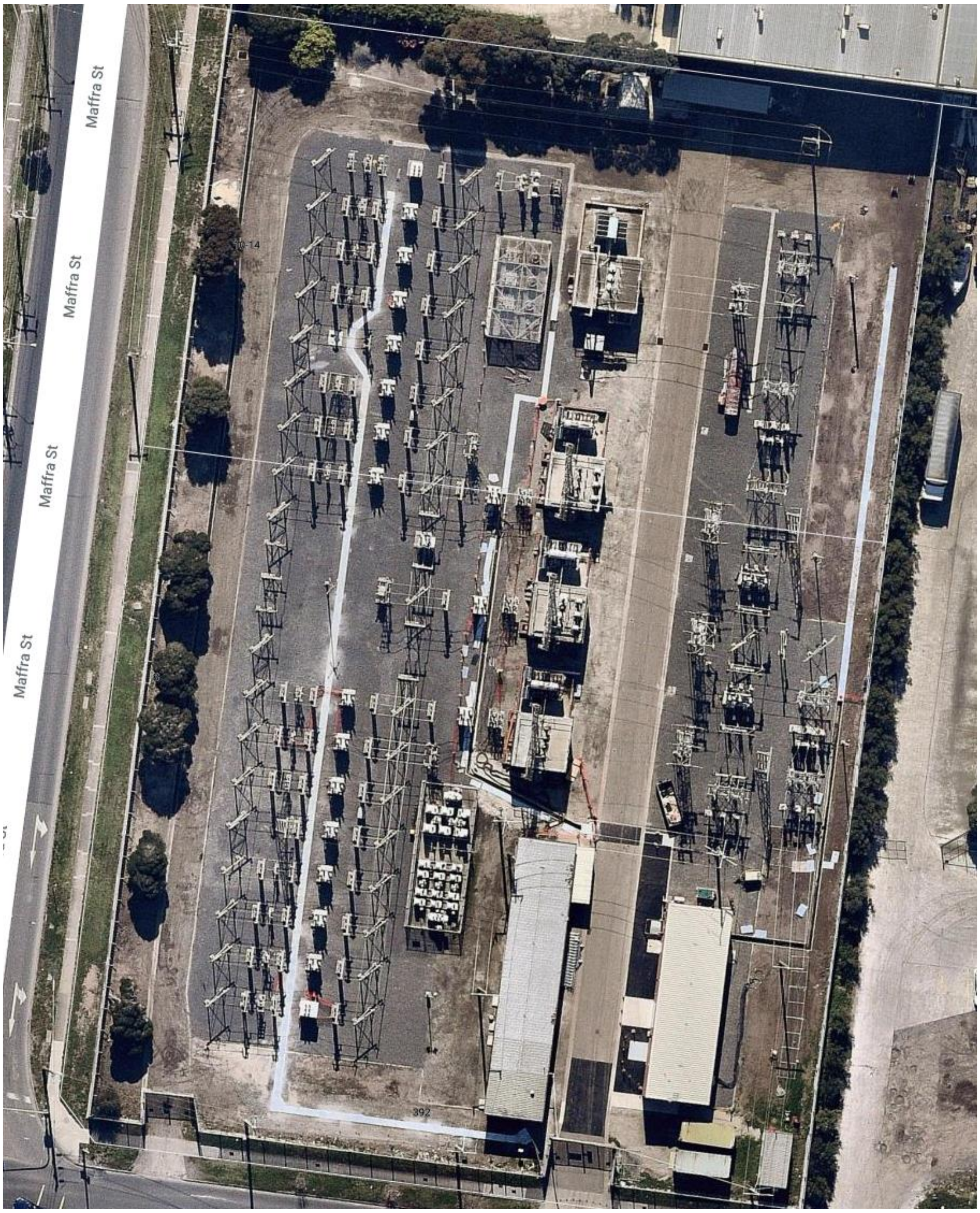
Zone Substation BD consists of the following major plant as shown in Table 2-2:

1. Three off 66/22kV 20/30MVA transformers (enclosed main tanks) and one off 66/22kV 20/33MVA transformer (enclosed main tank) supplied by 66kV sub-transmission lines from Thomastown Terminal Station (KTS), Visoboard Coolaroo (VCO) and Broadmeadows South (BMS) Zone Substations; and,

2. Outdoor 22kV switchyard consisting of three 22kV buses supplying fourteen 22kV feeders.

Refer to Appendix B2 for the Single Line Diagram.

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



2.1 ASSET DETAILS

The power transformers installed at BD are briefly described in Table 2-1 below. The transformer enclosures and 66kV bus is shown in Figure 2–3.

Table 2-1: Zone Substation BD Power Transformer Details

Transformer	Make	Voltage Ratio	NER Installed	Capacity	SECV Spec No.	Year of Manufacture
Transformer No.1	English Electric	66/22kV	Y	20/30MVA	64-65/288	1973
Transformer No.2	English Electric	66/22kV	Y	20/30MVA	64-65/288	1968
Transformer No.3	English Electric	66/22kV	Y	20/30MVA	64-65/288	1968
Transformer No.4	English Electric	66/22kV	Y	20/33MVA	Order No. 4549039762	2002

Figure 2–3: BD Transformer Enclosures and Radiators

The annual maximum demand at BD occurs in summer and is currently 93.6MVA. Summer refers to the period of 1 December of the previous year to 31 March. The N-1 station cyclic rating is 123.7MVA in summer. The actual and estimated maximum loading in the period 2016 to 2024 is shown in Table 2-2[2].

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

Table 2-2: BD Station Loading

Station Loading	Actual		Estimated						
	2016	2017	2018	2019	2020	2021	2022	2023	2024
Summer MVA	92.7	89.2	93.6	94.9	95.3	93.0	92.3	92.7	92.3

There have been thirty two recorded defects on the transformers at BD since 2009. A capex life extension project was initiated in 2013 and the lid gaskets of the No.1, No.2 and No.3 transformers were replaced, the 66kV bushings were also replaced during the lid gasket project. The defects are shown in Table 2-3.

Table 2-3: BD Transformers Defect History

Date	Asset	Defect	Remedy
28/04/2009	No.1 Transformer	Bushing Oil Level High	Investigate and Repair
16/11/2010	No.3 Transformer	Adjust Bushing Oil Level	Investigate and Repair
15/07/2011	No.1 Transformer	Leaking Oil	Tighten CT Secondary Studs
19/07/2011	No.2 Transformer	Leaking Oil	Tighten Gaskets
19/09/2011	No.1 Transformer	Leaking Oil	Tighten Gaskets
19/09/2011	No.3 Transformer	Leaking Oil	Tighten Gaskets
28/12/2011	No.3 Transformer	Leaking Oil	Tighten Gaskets
15/03/2012	No.2 Transformer	Leaking Oil	Tighten CT Secondary Studs
25/05/2012	No.1 Transformer	Leaking Oil	Tighten Gaskets
25/05/2012	No.3 Transformer	Leaking Oil	Tighten Gaskets
24/04/2013	No.3 Transformer	Low Oil	Top Up Oil
22/07/2013	No.1 Transformer	Faulty Ferranti Mechanism	Replaced Friction Drive Components
8/08/2013	No.2 Transformer	Out of Step OLTC	Investigate and Repair
28/10/2013	No.3 Transformer OLTC MECH	Out of Step OLTC	Investigate and Repair
5/12/2013	No.2 Transformer	Out of Step OLTC	Investigate and Repair
18/12/2013	No.1 Transformer	Leaking Oil	Tighten Gaskets
6/01/2014	No.2 Transformer OLTC MECH	Out of Step OLTC	Investigate and Repair
31/03/2014	No.2 Transformer DIV SW	Fixed & Moving Contacts in Poor Condition	Renew all Worn Moving and Fixed Contacts
15/07/2014	No.3 Transformer DIV SW	Low Oil	Top Up Oil
18/07/2014	No.2 Transformer	Silica Gel in Breathers Consumed	Replace Silica Gel
11/08/2014	No.2 Transformer OLTC MECH	Low Oil	Top Up Oil
20/08/2014	No.4 Transformer	Silica Gel in Breathers Consumed	Replace Silica Gel
9/10/2014	No.2 Transformer DIV SW	Faulty OLTC	Investigate, Repair and Replace Spare Parts
1/04/2015	No.1 Transformer OLTC MECH	Out of Step OLTC	Investigate and Repair

Date	Asset	Defect	Remedy
13/05/2015	No.2 Transformer	Faulty Ferranti Mechanism	Investigate and Repair
13/05/2015	No.3 Transformer	Faulty Ferranti Mechanism	Investigate and Repair
9/08/2015	No.1 Transformer	Low Oil	Top Up Oil
9/08/2015	No.2 Transformer	Low Oil	Top Up Oil
9/08/2015	No.3 Transformer	Low Oil	Top Up Oil
16/10/2017	No.3 Transformer	Leaking Oil	Tighten Bolts
14/05/2018	No.1 Transformer	Leaking Oil	Tighten Gaskets
14/05/2018	No.1 Transformer OLTC MECH	Leaking Oil	Tighten Bolts

Figure 2–4: No.2 Power Transformer Oil Leaks

2.2 ASSET RISK ANALYSIS

2.2.1 ASSET CONDITION

The transformers at Zone Substation BD undergo a condition based monitoring regime which is detailed in the Zone Substation Primary Plant Asset Class Strategy (ELE AM PL 0061). A summary of the Condition Monitoring Index for BD transformers is shown in Table 2-4.

Table 2-4: BD Transformer Condition Monitoring Index

Legend	Good	Test, Evaluate & Monitor	Initiate Life Extension Program or Replace

Test	Parameter	Transformer No.1	Transformer No.2	Transformer No.3	Transformer No.4
Paper Sample	Paper DP	292	253	594	n/a
Paper Sample	Moisture in Paper	6.29%	5.43%	5.41%	n/a
PDC/RVM	Oil Quality	Good	Good	Good	n/a
Oil Test	Moisture in Oil	12	13	14	5
Oil Test	Acidity in Oil	0.02	0.03	0.03	0.01
Oil Test	DGA	✓	✓	✓	✓
Oil Test	Dielectric	71	78	72	79
Oil Test	Interfacial Tension	28	29	28	36
Oil Test	Copper Sulphide	No	No	No	Yes

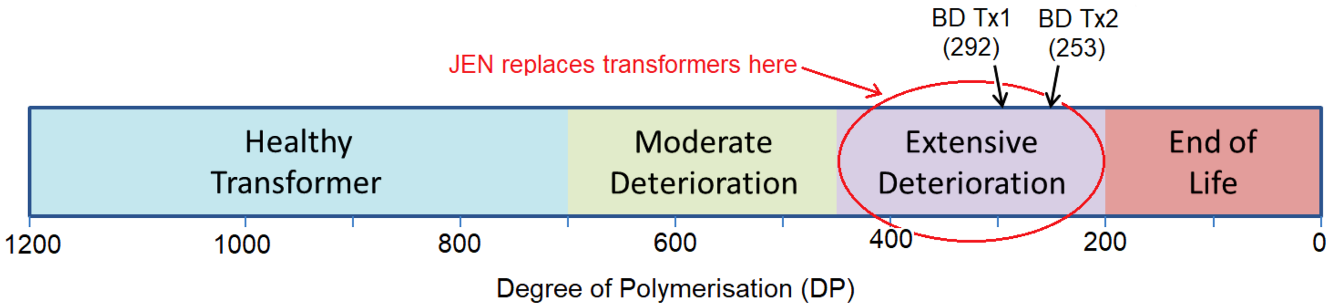
Three current issues associated with the BD transformers have been identified and are discussed below.

1. **Intrusive insulation paper samples taken from winding leads on the No.1, No.2 and No.3 transformers in 2013/14 by Select Solutions had a resultant DP (Degree of Polymerisation) of 292, 253 & 594 respectively. This is the critical issue.**

   The mechanical condition of the transformer paper insulation will usually determine when a transformer is at end of life as this degradation is not reversible and when the condition has reached a poor state, there is no economic corrective action to maintain the performance of the transformer. It is at this time that major refurbishment (if practicable and economic) or replacement of the transformer will be required. The determination of “end of life” is not absolute.

   Currently the accepted method of life assessment for transformers is Degree of Polymerisation (**DP**) which quantifies transformer paper condition. While the determination of “end of life” is not absolute, a DP value of between 200 and 450 signifies that a transformer’s insulation has experienced extensive deterioration and should be scheduled for replacement before failure occurs. A DP value less than 200 signifies a transformer has reached end of life and is unreliable. The No.1 and No.2 transformers’ paper is extensively deteriorated as shown below.

Figure 2–5: Degree of Polymerisation Index



The paper samples at zone sub BD were taken from leads located within the top of the main tank, but DP values will be significantly lower within the transformer windings. Statistically it can be expected that failure rates will increase quite rapidly as a result of the transformers present condition.

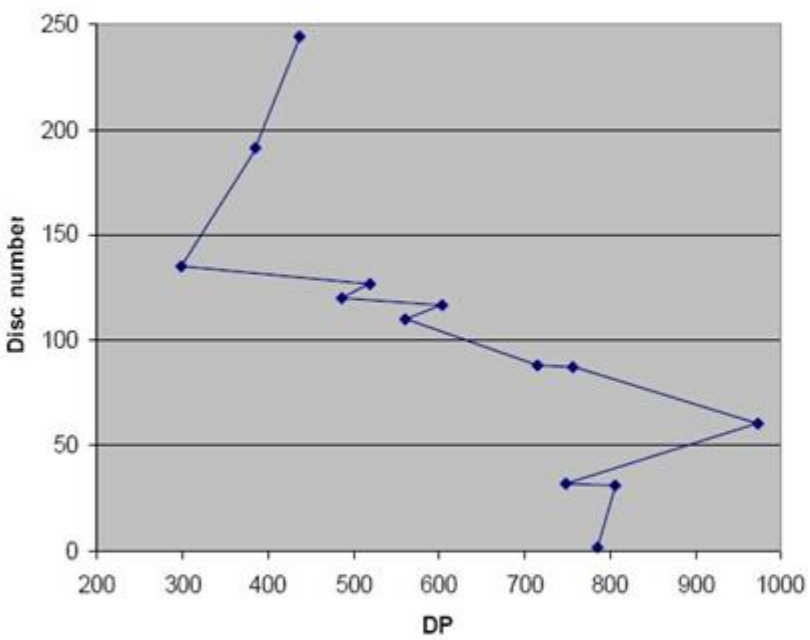
In addition the degradation of paper of a small localised area of insulation in the vicinity of the hottest spot within the transformer winding can be just as terminal as the degradation of the entire winding insulation. The DP of the No.1 and No.2 transformers at BD can be as low as 150 within the hottest spot of the winding which is well below industry standard.

The figure below shows the results from paper sample DP measurements taken from different positions along the height of the winding of a dismantled transformer.

The DP value can vary significantly within a transformer:

- The hottest part of the transformer – the middle of the winding – exhibits the lowest DP value.
- The insulation at the base of the transformer remains cool for most of its life and typically suffers little degradation.

Figure 2–6: Degree of Polymerisation along a Transformer Winding



The paper samples from the two transformers confirm the mechanical strength of the cellulose has deteriorated and is placing the transformers at risk of failure. A close in feeder fault will impose mechanical stress on the winding and may tear the paper and reduce the electrical insulation, resulting in a catastrophic transformer failure. This is the critical issue.

It should be noted that the No.1 and No.2 transformers at zone sub BD are 45 and 50 years old respectively and so the poor condition of the paper insulation is not surprising. The replacement plan aligns with the Primary Plant Asset Class Strategy (ELE AM PL 0061) which states "although some transformers have continued to operate satisfactorily for over 50 years, a 50-year-old transformer is approaching the end of its practical life." Furthermore, the strategy also states that "achieving at least a 50 year service life will maximise the economic life of the asset and this will result in lowest costs to the customer."

It should also be noted that these DP results were obtained by testing actual insulation paper samples rather than relying on an estimated DP result from such techniques as Furan Analysis or Polarisation and Depolarisation Current & Recovery Voltage Measurements (See ELE AM PL 0061, Appendix A, for further explanation). The test results are shown in Table 2-5 below.

Table 2-5: BD Transformer Paper Sample Test Results

Tests	Transformer No.1			Transformer No.2			Transformer No.3		
	R Ph	W Ph	B Ph	R Ph	W Ph	B Ph	R Ph	W Ph	B Ph
Degree of Polymerization (DP)	284	285	307	237	n/a	268	588	571	624
Average DP	292			253			594		
Moisture Content of Paper Sample	6.48%	6.83%	5.56%	5.24%	n/a	5.62%	5.01%	4.81%	6.42%
Average Moisture Content	6.29%			5.43%			5.41%		

2. **Intrusive insulation paper samples taken from the winding leads of the No.1 and No.2 transformers in 2013 by WTC and TJ H2b determined moisture content of paper sample at time of testing at 20°C to be 6.3% and 5.4% respectively.**

A transformer's moisture content is a significant indicator of the transformer's condition and a major contributor to the rate of ageing of the paper insulation. A water content of 2.2% in insulation is classed as moderately wet[3]. Moisture in insulation deteriorates the dielectric withstand strength, increases the rate of cellulose ageing, and in the case of excessive temperatures generates gas bubbles. That is why moisture content in insulation of power transformers should be monitored.

The No.1 and No.2 transformers at BD have moisture contents of 6.3% and 5.4% respectively. This indicates that the paper insulation is extremely wet and the condition of the paper is severely deteriorated. This is also a critical issue.

To remove the moisture the transformers would have to be de-tanked and dried out, core tightened, gaskets changed and re-commissioned. This process is labour intensive and expensive. At the end of the process the transformer would still be >50 years old and have poor mechanical strength due to the degraded kraft paper used to insulate the windings and associated components.

[3] Limits for water content are defined in the IEC 60422 standard.

When a transformer is out of service, operating the remaining aged and deteriorated transformer at full capacity with low DP values and high moisture in paper is not ideal because it presents a higher probability of failure. Operating the transformers at high temperatures will increase the likelihood of a turn-to-turn fault occurring within the windings. This will have a direct effect on network performance and strengthens the case for the AER to approve the replacement of the transformers.

3. The transformers have a history of oil leaks on the main tank and radiators.

This is not an issue that is driving the replacement of the transformers however it does require elevated levels of operating expenditure to manage. The oil leaks make the transformers maintenance intensive. A capex life extension project was initiated in 2013 and the lid gaskets of the No.1, No.2 and No.3 transformers were replaced, however the oil leaks have not completely stopped. By replacing the transformers, the maintenance costs could be minimized and used to offset the cost to replace the transformers.

The following options to address these issues have been considered.

1. Do nothing
2. Increased maintenance & monitoring
3. Transformer refurbishment
4. Transformer re-wind
5. Transfer load
6. Replace one transformer
7. Replace two transformers
8. Non-network solutions

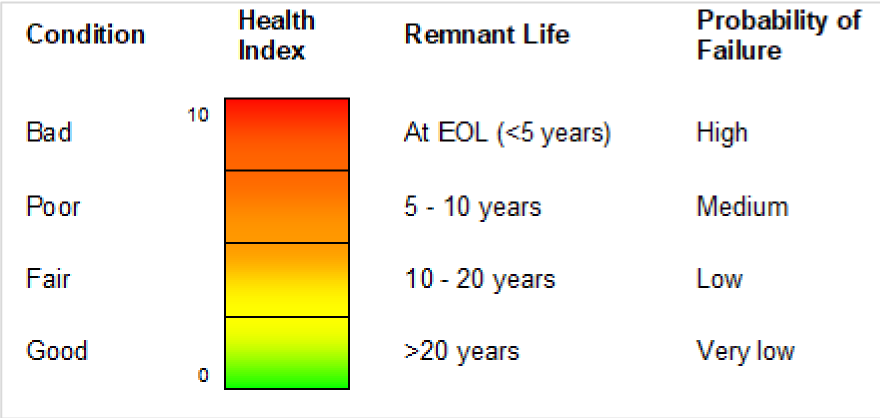
The option of a non-network solution (e.g. demand management and/or embedded generation) is not an alternative for removing the asset condition risk at the zone substation.

2.2.2 CONDITION BASED RISK MANAGEMENT MODELLING RESULTS

Condition Based Risk Management (**CBRM**) is a technique for power transformer assets used to assist in the development of asset investment plans using existing asset data and other relevant information. A description of the model and the results for zone substation related assets is in document 'Jemena CBRM Report – Zone Substation Assets'.

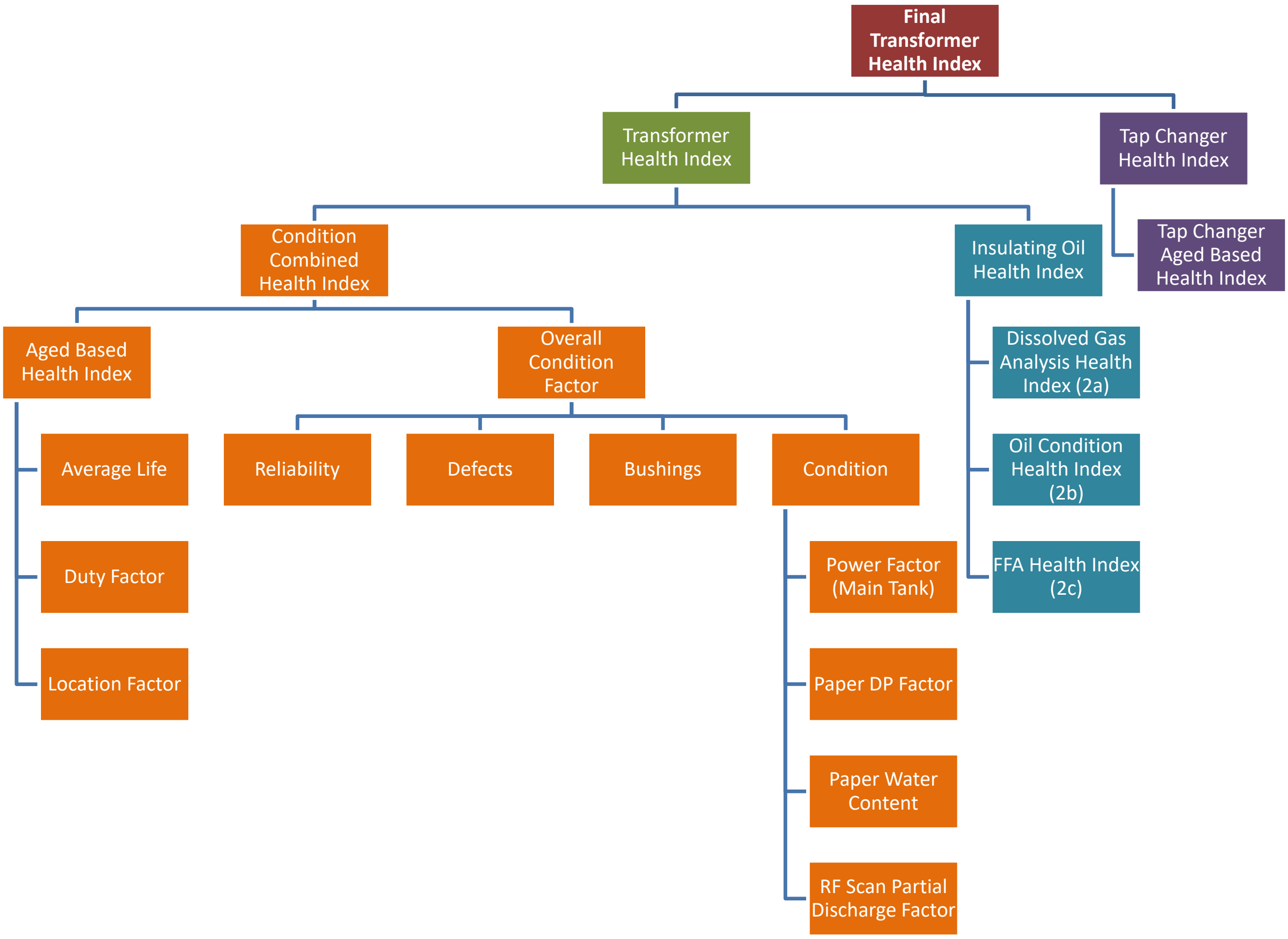
CBRM uses a Health Index for each asset based on a scale from 0 to 10. Values of health index in excess of seven represent serious deterioration. The CBRM Health Index is a numeric representation of the condition of each asset. Essentially, the health index of an asset is a means of combining information 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 2–7.

Figure 2–7: CBRM Health Index



The inputs used for transformer assessment modelling are shown in Figure 2–8.

Figure 2–8: Power Transformer Health Formulation



The CBRM modelling shows that if BD ZSS No.1 and No.2 transformers are not replaced they will have a health index of **7.01** and **7.67** respectively in 2025. These HI values are at the extreme end of the scale and indicate that both transformers are in poor condition with a high probability of failure, compromising network performance and placing customer supply at risk.

2.2.3 FAILURE MODES

The cause of transformer failure can include:

- Insulation failure;
- Winding failure;
- Overloading;
- Oil degradation;
- Lightning and other line surges;
- Inadequate maintenance; and
- Design/manufacturing errors.

A transformer can fail due to thermal, electrical or mechanical factors however whilst a typical failure mode is difficult to predict, most failures result from a breakdown of the transformer's insulation system.

A likely mode of failure will be inter-turn winding insulation failure as a result of the mechanical forces created by a fault within or downstream of the transformer. The insulation paper will not have the mechanical strength to maintain the required insulation during winding deformation.

In order to develop a risk cost associated with a permanent failure of the No.1 and No.2 power transformers at Zone Substation BD, a likelihood of failure and associated consequence of failure has been developed.

2.2.4 LIKELIHOOD OF FAILURE

The probability of a permanent transformer failure at Zone Substation BD has been modelled using Perks' formula. The formula is purely an age based model which compares transformer age to likelihood of failure. It is used as a benchmarking tool, where failures based on aging can be used to calculate the cost of a risk. Further explanation of the model is outlined in Appendix C.

The model has predicted that the current probability of a single power transformer catastrophic failure to be 7-11% per annum at Zone Substation BD. This is determined from the Transformer Failure Rate Function. The model's curve indicates that the transformers at Zone Substation BD are in the region where failure rates are increasing exponentially. The model indicates by 2022 the failure rate probability will increase to 9-14% per annum. Due to the load at risk and safety issues associated with a catastrophic failure this is an unacceptable level of risk.

The correlation between calendar age and insulation deterioration is subject to some uncertainty. The Perks Model is a statistical model and does not take into account other conditions such as manufacturing differences and loading history, it is a second order check of the business case. Ultimately condition monitoring tests (i.e. DP) are used to justify the replacement of the transformers.

In this business case it is assumed that the failure rate of one transformer is independent of the others. There is however, a possibility that the two transformers could fail simultaneously as they are all connected in parallel, however this scenario has not been modelled. If multiple transformer failures were to occur the business case for replacement would be all the more supported.

2.2.5 CONSEQUENCE OF FAILURE

The worst case consequence of failure would include a transformer fire. The consequence of a transformer fire can be catastrophic as shown in the following three examples:

- On 14 October 2012 a transformer at the Hume power station (commissioned 1958) faulted and caught fire. Delays in isolating the station resulted in the transformer burning for two hours before crews could begin to extinguish the fire. 500 people were evacuated from the surrounding area due to smoke conditions. The fire was not extinguished until the next morning.
- On 26 November 2004, the DVY No.3 Transformer in Dandenong (commissioned in 1999) exploded and caught fire. Porcelain debris was found up to 50 meters away from the transformer in the 66kV switchyard, in the neighbouring tile shop and in the car park. The main transformer and its associated equipment including the transformer cables, control cables, civil works, 66kV and 22kV neutral isolators were completely destroyed. There was also damage to the adjacent No.2 mobile transformer affecting the transformer cables, control cubicle, tires and electronic equipment.
- On 10 September 1989 the No.2 and 3 transformers at the Union Road substation (commissioned 1958) in Albury exploded and caught fire and as a result were completely destroyed. The generation of heat was such that the fire in the No.3 transformer was not extinguished until 12 hours after the fault.

From a business and asset management perspective it is prudent that the condition of assets installed on the network is maintained to ensure HV outages are minimized and OH&S regulations are met. Addressing the elevated risk of transformer failure aligns with the current JEN strategy and plans.

A risk assessment has highlighted five prominent risks as per 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 zone substation. The asset condition risk would remain until the assets are either replaced or decommissioned.

A comparison of the eight options listed above and the issues they address is shown below.
Table 3-1: Options Analysis. By implementing this project these risks are mitigated to an acceptable level/rating, illustrating the need for the business to undertake the project.

The direct costs associated with such catastrophic failures have been identified as:

- Network Performance (STPIS);
- Operating Expenditure (OPEX), and
- Capital Expenditure (CAPEX).

For a transformer failure at Zone Substation BD, each of these costs are further explained and developed below.

Network Performance

Previous experience (DVY and Albury) has shown that catastrophic transformer failure resulting in fire and smoke can require the zone substation to be totally off supply whilst the fire is extinguished and this may take up to 12 hours. Once the fire is extinguished it can take another six hours of repair work to adjacent assets before supply is restored.

For modelling purposes it is assumed supply could be restored in 18 hours.

The network performance impact (STPIS) associated with this scenario based on a SAIDI cost of $0.90 per minute off supply and a SAIFI cost of $56.56 per customer off supply, would be:

18(hrs) x 60(mins) x $0.90/min + 13,311(Customers supplied from ZSS BD) x $56.56/Cust = $754k.

Note that the restoration time has little impact on the figure, as even if the outage time was reduced to six hours, the figure would only be reduced by $1k.

CAPEX

The capital expenditure associated with a single permanent failure is estimated to be $3.9M (2019). This represents the equipment replacement cost and new civil works (including disposal of replaced transformer).

This capital expenditure figure is based on historical replacement costs.

OPEX

The operating expenditure associated with a single permanent failure is estimated to be $0.608M (real). This represents the operating costs associated with the forced outage resulting from the transformer failure. This cost has been derived using the historical data from the DVY (Dandenong Valley) transformer failure in 2004. It includes activities such as network operations to restore supply, environmental remediation after oil spill, clean-up of fire damage, structural damage repairs (including repairs to the adjacent transformer) and other safety related costs.

Table 2-6: DVY Transformer clean-up cost

DVY Clean Up Costs	
Activity	**Cost (2019$)**
Demolition work by Wilsons Transformers	$20,099
Damage to adjacent plant	$19,568
22kV cable replacement	$20,711
66kV isolator replacement	$24,570
Surge arrestor replacement	$5,844
NPS charges	$197,145
Design & drafting	$48,599
SCADA	$8,986
Miscellaneous	$45,213
2004 Costs	$390,735
years (2004-2020)	16
Inflation (from Reserve Bank)	2.8%
2020 (real $)	$607,816

Total Cost of Risk

The worst case cost of risk for a transformer failure has been determined using the results outlined in Table 2-6. This represents the annual potential impact.

Cost of Risk p.a. = ($ Network Performance + $ CAPEX + $ OPEX) x Probability

= ($754k + $3,900k + $608k) x 11%

= $578k p.a.

The worst case cost of risk for a transformer failure has also been determined using the results outlined in Table 2-6 in conjunction with a failure rate for 2022 into the future. This represents the annual potential impact.

Cost of Risk p.a. = ($ Network Performance + $ CAPEX + $ OPEX) x Probability

= ($754k + $3,900k + $642k) x 14%

= $741k p.a.

2.3 SMART SUBSTATION OPPORTUNITIES

Keeping pace with the changing landscape of the electricity grid and the advent of the smart substation, the following technologies were considered from a primary plant perspective:

- Transformer fibre optic winding temperature sensors
- Transformer online bushing PD monitoring
- Transformer online temperature & moisture monitoring
- Online monitored zone substation security system

The transformer that will be supplied for this project will have the fibre optic winding temperature sensors embedded. This will allow an accurate determination of the winding hotspot to enable JEN to operate the transformers more effectively, especially in times of extreme demand.

Transformer bushing PD monitoring is also recommended for the new No.2 BD transformer as an innovation pilot project on the JEN network as the incremental cost to avail this technology is rather small as the field resources would already be mobilised on site allowing us to gain synergies that would result in cost saving.

Transformer online temperature & moisture monitoring by Aurtra will be implemented for the new No.2 and the existing No.3 and No.4 transformers. This will provide us with valuable information about the transformers as their loading varies.

The cost to implement the above mentioned technologies would be far more cheaper if done as part of this project. Retrofitting the above at a later stage would cost more.

During major construction works in zone substations Jemena has experienced recurring unauthorised entries and theft of valuable power tools, HV test sets[4] and materials. It is recommended that we install security video cameras on site during the construction with back to base monitoring will help prevent (and help recover) the theft of valuable tools and equipment. After the completion of the construction of the project the system will be left on site to monitor any unauthorised entry to the zone substation.

4 In 2017 at AW zone substation a HV test set valued at $100,000 was stolen

2.4 PROJECT OBJECTIVES AND ASSESSMENT CRITERIA

2.4.1 OBJECTIVE

The objective of the project is to determine the most appropriate strategy for the transformer assets at Zone Substation BD 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.

Eight 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 risk assessment from Section 2.2 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.

2.4.2 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 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.

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****.*

The section of the Environment Protection Act 1970 (No.8056 of 1970, Part **III** – Environment Protection) relevant to this project is:

Section 27A – Offences relating to industrial waste

(1) A person who—

(a) contravenes any rules or requirements relating to industrial waste specified in a waste management policy; or

(b) contravenes any regulations relating to industrial waste; or

(c) causes or permits an environmental hazard—

is guilty of an indictable offence.

Penalty: 2400 penalty units plus, in the case of a continuing offence, a daily penalty of 1200 penalty units for each day the offence continues after conviction or after service by the Authority on the accused of notice of contravention of this subsection (whichever is the earlier).

Note: The values for the 2018–19 financial year were gazetted (Victoria Government Gazette Number S 145; PDF 301KB) on 29 March 2018 and are as follows: One fee unit = $14.45, One penalty unit = $161.19.

JEN must also comply with the Environment Protection Act (1993) as well as the updated bunding guidelines (EPA bunding guidelines 347.1) released by the EPA in 2015, as it seeks to reduce the risk of failing equipment causing significant environmental impact.

In respect to power transformers, JEN seeks to comply with these regulatory obligations through the development and implementation of its Zone Substation Primary Plant Asset Class Strategy. JEN must also comply with the State Environmental Protection Regulation (Control of Noise from Commerce, Industry and Trade No. N-1 (SEPP N-1).

2.4.3 ASSESSMENT CRITERIA

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

2.5 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 NAMP and annual planning reports.

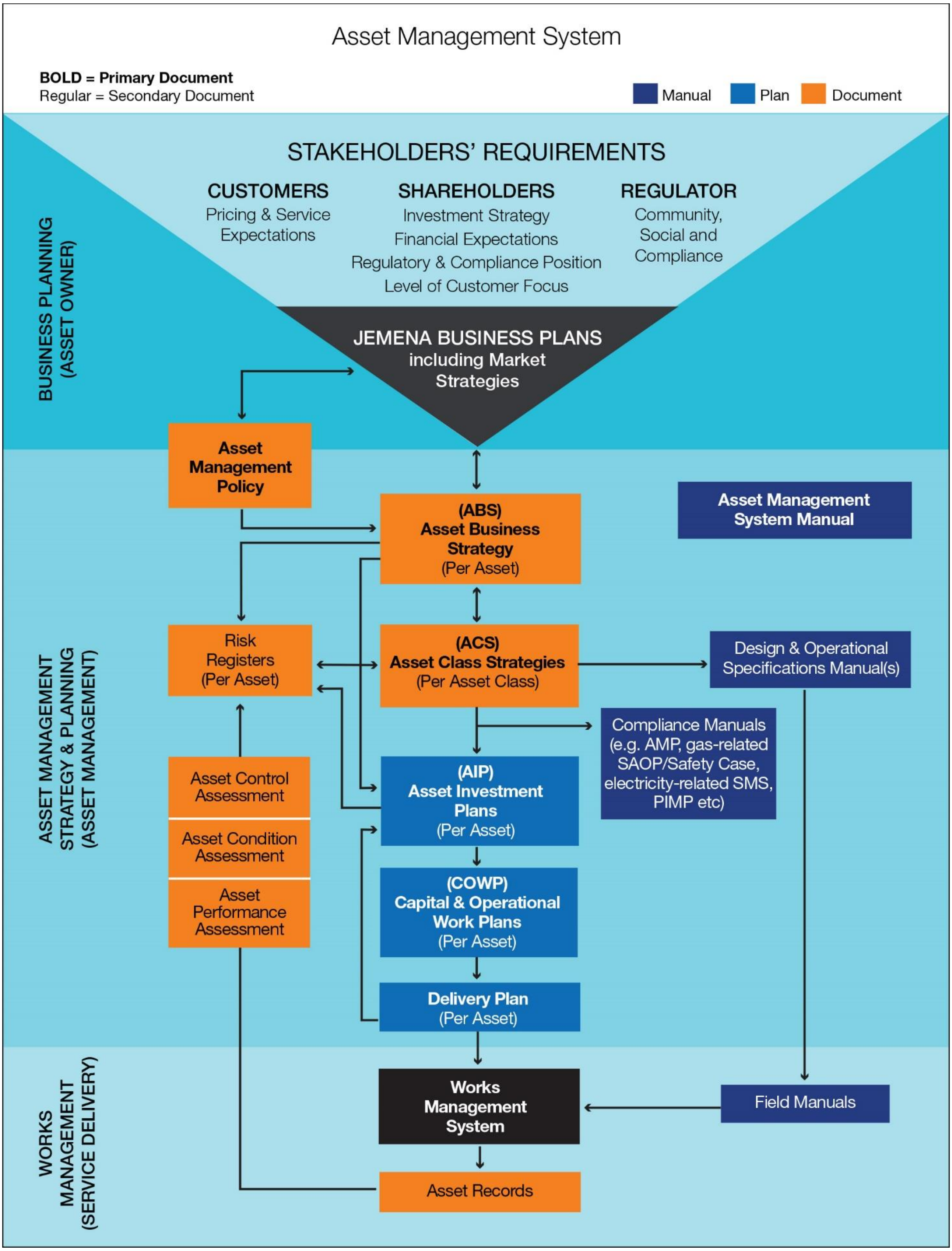
JEN must comply with regulatory obligations; these are incorporated into the development and implementation of its Zone Substation Primary Plant Asset Class Strategy (ELE AM PL 0061). The Asset Class Strategy creates a line of sight between the JEN Business Plan and the Asset Management Plan.

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. By completing this project, JEN can reduce its exposure to the possibility of litigation by authorities due to an injury or environmental incident.

Figure 2–9 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 2–9: The Jemena Asset Management System



3. CREDIBLE OPTIONS

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

3.1 IDENTIFYING CREDIBLE OPTIONS

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

1. Do Nothing
2. Increased Maintenance and Monitoring
3. Transformer Refurbishment
4. Transformer Rewind
5. Transfer Load
6. Replace One Transformer
7. Replace two Transformers
8. Non-Network Solutions

Option 6 will also include the replacement of the No.2 22kV Transformer CB.

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 unless stated otherwise. 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 zone substation. The asset condition risk would remain until the assets are either replaced or decommissioned.

A comparison of the eight options listed above and the issues they address is shown below.

Table 3-1: Options Analysis

Issues	Option 1 Do Nothing	Option 2 Increased Maint. & Monit.	Option 3 Transformer Refurbishment	Option 4 Transformer Rewind	Option 5 Permanent Load Transfer	Option 6 Replace One Transformer	Option 6 Replace Two Transformers	Option 7 Battery Bank
Issue 1 Insulation Paper	○	○	○	●	●	●	●	○

Issues	Option 1 Do Nothing	Option 2 Increased Maint. & Monit.	Option 3 Transformer Refurbishment	Option 4 Transformer Rewind	Option 5 Permanent Load Transfer	Option 6 Replace One Transformer	Option 6 Replace Two Transformers	Option 7 Battery Bank
Issue 2 Insulation Paper Moisture	○	○	○	●	●	●	●	○
Issue 3 Transformer Oil Leaks	○	●	●	●	●	●	●	○
Issue 4 Safety Risk - Catastrophic Failure	○	◑	●	●	●	●	●	○
Issue 5 Customer Reliability	○	◑	●	●	●	●	●	○
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 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 at BD including inspections, preventive work and repair of defects.

The risk of a transformer fault is increasing as the insulation properties continue to deteriorate. Under this option the transformers will be replaced when they fail. However, this has safety, operational and environmental consequences. Consequences may include:

- Interruption/loss of supply to customers supplied from the station;
- Injury to JEN employees and contractors;
- Damage to the transformer and adjacent assets, and;
- Environment issues (i.e. loss of significant amount of oil).

This option would allow management of the oil leaks issue (Issue 3) but would be unlikely to solve it. The option does not address any of the other two transformer condition issues described in Section 2.2. In particular, the paper insulation condition (Issue 1) would not be resolved.

The do nothing option is an endorsement of a run to failure strategy that is not consistent with the Primary Plant Asset Class Strategy adopted for this type of plant. This is not appropriate for this type of infrastructure given the consequences of failure for the business and for the community.

These scenarios will affect the performance indicators of JEN and have financial implications such as increased cost for replacement of the transformer, loss of performance incentives and the cost of potential injury to employees. This option is reactive by nature and does not address any of the current issues.

3.2.2 OPTION 2 - INCREASED MAINTENANCE & MONITORING

Under this option, the transformers at BD would be more closely monitored and the frequency and range of condition testing would be increased. Re-conditioning of the insulating oil may address any oil related issues and issues with bushings could be remedied before they developed to any significant degree.

This option does not address either of the paper insulation condition issues and the probability of failure.

3.2.3 OPTION 3 - TRANSFORMER REFURBISHMENT

This option involves removal of the windings, drying out the windings, tightening up of all internal components and reassembly with re-conditioned oil. The issues with transformer oil condition would be addressed. This refurbishment would be undertaken on site or in a workshop.

This option does not address the paper insulation condition (Issue 1 and Issue 2) and the probability of failure of the transformer would remain.

This option does not solve the reliability, safety or environmental issues and is anticipated to cost approximately $500k. Essentially there will still be one power transformer remaining in service that is at the risk of failure.

3.2.4 OPTION 4 - TRANSFORMER REWIND

Transformer rewind involves removal of the transformer from site to a transformer manufacture facility. The core and windings would then be de-tanked and the windings removed from the core. New windings would be manufactured and the unit would then be re-assembled, tightened and filled with new oil.

Wilson Transformers have estimated that the cost to undertake this work would be approximately 80% of the cost of a new transformer and the work would take approximately 4 months per transformer.

Wilsons also indicated that the manufacturing cost of a new transformer would be approximately $600k so rewinding of the transformer would represent a saving of $162k per unit compared to option 6. Hence the total cost for this option including civil works is $3.9M.

Undertaking this option would mean that for a period of 4 months, BD would be operating with only three transformers in service, one of which would have a severely deteriorated condition, while the No.2 transformer is being refurbished offsite. The loss of the in service transformer at any time during these periods would result in loss of supply to half of the zone substation for the period of one hour. Full restoration of load could be achieved by transfer of load, however any further faults on the incoming 66kV lines or the in-service transformers would result in customer outages. These customers would be off supply until the fault was rectified and/or the plant was repaired. This repair could take days or even months depending on the nature of the failure.

Moreover, this option will result in other legacy issues remaining which include:

- Transformer oil in the ground;

- Outdated and inefficient transformer radiator design, and
- Outdated and aged transformer equipment that includes core, on-load tap-changer, current transformers etc.

3.2.5 OPTION 5 - TRANSFER LOAD

The transfer load option involves the transfer of load from BD and the temporary or permanent retirement of the zone substation.

Table 2-2 shows that the current maximum demand at BD is 93.5MVA. The current transfer capacity away from BD to surrounding zone substations is approximately 40.8MVA.

This option would however require the creation of at least 100MVA (n-1) of capacity within a couple of kilometres of ES. This could be achieved by installing extra transformer capacity at an existing zone station or the construction of a new substation in the area.

In addition to the transformer costs, this option would require installation of new transformer bays including transformers, circuit breakers, 22kV feeder circuit breakers and the establishment of new 22kV feeders. A new or extended control building would be required to house all associated protection and control equipment.

The only adjacent zone substations where extra capacity could possibly be installed are Broadmeadows South (BMS), Coolaroo (COO) or Somerton (ST). ST is a three transformer substation and there is not enough space to accommodate a fourth. There is space for a third transformer at BMS and COO but not enough for a fourth or fifth.

Establishment of a greenfield zone substation is estimated to be $14.328M and this is based on the approved business case for zone substation YVE. YVE was commissioned in 2014. Adjusting for CPI increases from 2014 to 2020, this cost becomes $16.9M in 2020. This estimate is conservative due to the costs associated with reconfiguration of 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.

The establishment of a new zone substation to replace BD would not be a prudent method of addressing the existing transformer condition issues at BD. The cost of this establishment would be far in excess of the cost to replace the transformer at BD.

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

3.2.6 OPTION 6 - REPLACE ONE TRANSFORMER

This option involves replacing the existing No.2 transformer with new modern equivalent and installing it to current standards. The existing No.1 transformer would be made a hot standby to cover for any load shortfall if any of the other existing transformer/s were out of service. The load growth at BD doesn't warrant the replacement of both the No.1 and No.2 transformers with new modern equivalents. The replacement of only one transformer is adequate from a station loading perspective.

This option would address all the condition issues identified in Section 2.2 and resolves the associated safety and reliability issues.

The risk to network performance would be minimised as the station load is well below the station N-1 rating and there is 40.8MVA of emergency transfer capacity available in 2018. The changeover from old to new would take approximately three days with no planned customer outages.

The following high level equipment will be installed in conjunction with the new power transformer:

- Transformers
  - The No.2 transformer is to be replaced with 20/33MVA 66/22kV Yyn0d11 transformer;

- The transformers will have in-tank vacuum type tap changers;
- The 22kV cable box must be sized to contain a minimum of two 630mm2 copper XLPE cables per phase;
- Installation and termination of the 22kV transformer cables (minimum of three 1/c 630mm2 Cu XLPE per phase to their respective circuit breakers) are to achieve a 1250A two-hour rating, and
- Each transformer shall be supplied with Fibre Optic Sensors to measure the winding hot spot temperature and will be connected to the DRMCC. Asset Management will work with the Project Manager to evaluate this requirement with the transformer manufacturer.

- 66kV Equipment
  - Replacement of 66kV hardware;
  - No.2 transformer 66kV Disconnectors/earth switches;
  - Install No.2 66kV bus earth switches, and
  - No.2 transformer 66kV surge diverters.
- 22kV Equipment
  - No.2 transformer 22kV circuit breaker is to be replaced with a new 22kV metal enclosed, outdoor vacuum dead tank circuit breakers.
- Cables
  - Installation and termination of the No.2 transformer 22kV cables (minimum of 2x 1/c 630 mm^2 Cu XLPE per phase to their respective circuit breakers to achieve 1,250 A minimum cyclic rating).

This option addresses the condition issues identified in Section 2.2 and the risk to network performance would be minimised. This option meets all the technical and financial requirements, and is the preferred prudent option. The cost of this option is estimated to be $4.1M ($2019).

3.2.7 OPTION 7 – REPLACE TWO TRANSFORMERS

This option involves the replacement of both the No.1 and No.2 transformers with new modern equivalents and installing them to current standards. The annual maximum demand at BD occurs in summer and is currently 94.9 MVA. The N-1 station cyclic rating after the replacement of both the No.1 and No.2 transformers will be 129 MVA in summer. The estimated maximum loading at zone sub BD, up until 2025, doesn't increase beyond 96MVA and is well below the N-1 station cyclic rating of 129MVA.

While this option does address the condition issues identified in Section 2.2 and meets the technical requirements, it fails to meet the financial prudency criteria. The load growth at BD doesn't warrant the replacement of both the No.1 and No.2 transformers with new modern equivalents. The replacement of only the No.2 transformer will be adequate from a station loading perspective. This option is therefore not considered a prudent option.

3.2.8 OPTION 8 – 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 BD Transformer 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);
- 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), and

Load curtailment a reduction in consumption during a defined time period. This includes both ceasing to (in part or full) to consume electricity as well as shifting consumption to outside the critical time 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	Option 6
Total Expected costs	0	3,979	16,000	4,141
Total Expected market benefits	-	52,186	42,873	52,944
Net market benefits	-	48,207	26,873	48,803
Option ranking	4	2	3	1

On the basis of above economic analysis, Option 6 is the preferred option.

5. PROJECT TIMING

There are currently 7 zone substation transformers in service that were installed prior to 1960. A further 15 were installed over a 10-year period between 1960 and 1970 and these will reach 50 years of age, or older, over the next 2 years. The condition of all these units will be monitored and prioritised for replacement.

There are currently three zone substations with significant transformer condition issues on the Jemena Electricity Network. Replacement projects have been prioritised based on their criticality using current condition based test results and CBRM results. These project timings are consistent with the Zone Substation Primary Plant Asset Class Strategy (ELE AM PL 0061). These projects and their anticipated commencement years are:

- Zone Substation Fairfield (FF) (Installed 1950) – 2018/19;
- Zone Substation Essendon (ES) (Installed 1965) – 2019/20; and
- Zone Substation Heidelberg (HB) (Installed 1966) – 2020/21.

Consequently, this project is scheduled to commence in 2021 and to be completed in 2022.

6. REGULATORY TREATMENT

The rationale for this project is to maintain rather than improve network performance 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 transformers at Zone Substation BD.

If the asset remains in service, its condition will deteriorate and it may impact employee safety, while the reliability of customer supplies will decrease.

JEN notes that project costs of this nature have been funded in the EDPR capex allowance and there is no project costs between other assets. Prudent spend of allowance is evident as some options were discarded, while the most efficient of the remaining options has been recommended.

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.

7. RECOMMENDATION

This business case proposes a total investment of $4.1M (real 2019$) and requires Managing Director's (Band B) approval under the SGSPAA DFA Manual, Annex 3.

It is recommended that Option 6 be adopted and the No.2 transformer at zone sub BD be replaced with new modern equivalent installed to current standards. This option is considered prudent, and provides maximum net market benefit and is the preferred option, and will address all know 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 project would commence in 2021. The transformer will then be over 52 years old.

Appendix A
Asset Class Strategy

Jemena

A1. ELECTRICITY PRIMARY PLANT ASSET CLASS STRATEGY – ELE AM PL 0061

http://ecms/otcs/cs.exe/link/307787079

Appendix B
Project Scope and Delivery Information

B1. 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 herein.

TRANSFORMERS

- The No.2 transformer is to be replaced with 20/33MVA 66/22kV Yyn0d11 transformer;
- The transformers will have in-tank vacuum type tap changers;
- The 22kV cable box must be sized to contain a minimum of two 630mm2 copper XLPE cables per phase;
- Installation and termination of the 22kV transformer cables (minimum of three 1/c 630mm2 Cu XLPE per phase to their respective circuit breakers) are to achieve a 1250A two-hour rating, and
- Each transformer shall be supplied with Fibre Optic Sensors to measure the winding hot spot temperature and will be connected to the DRMCC. Asset Management will work with the Project Manager to evaluate this requirement with the transformer manufacturer.

66KV EQUIPMENT

Replacement of 66kV hardware, including:

- No.2 transformer 66kV Disconnectors/earth switches;
- Install No.2 66kV bus earth switches, and
- No.2 transformer 66kV surge diverters.

22KV EQUIPMENT

No.2 transformer 22kV circuit breaker is to be replaced with a new 22kV metal enclosed, outdoor vacuum dead tank circuit breakers.

CABLES

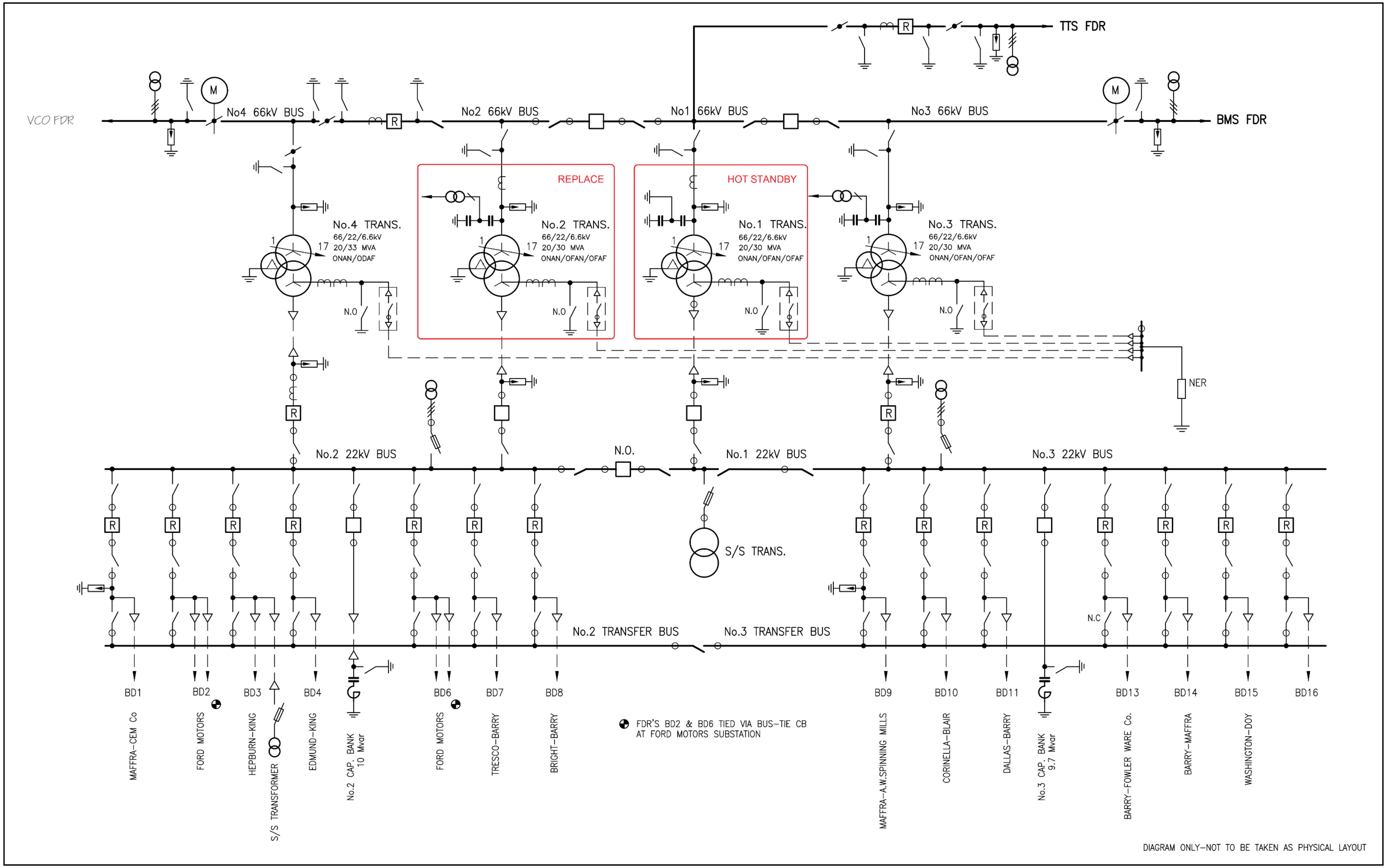
Installation and termination of the No.1, No.2 and No.3 transformer 22kV cables (minimum of 2x 1/c 630mm^2 Cu XLPE per phase to their respective circuit breakers to achieve 1250A minimum cyclic rating).

EARTHING

Augmentation of the existing earthing:

- CMEN bonding of feeder cable screens in accordance with standards.

B2. SINGLE LINE DIAGRAM



Appendix C
Transformer Failure Rate Modelling

C1. TRANSFORMER FAILURE RATE MODELLING FOR COST OF RISK

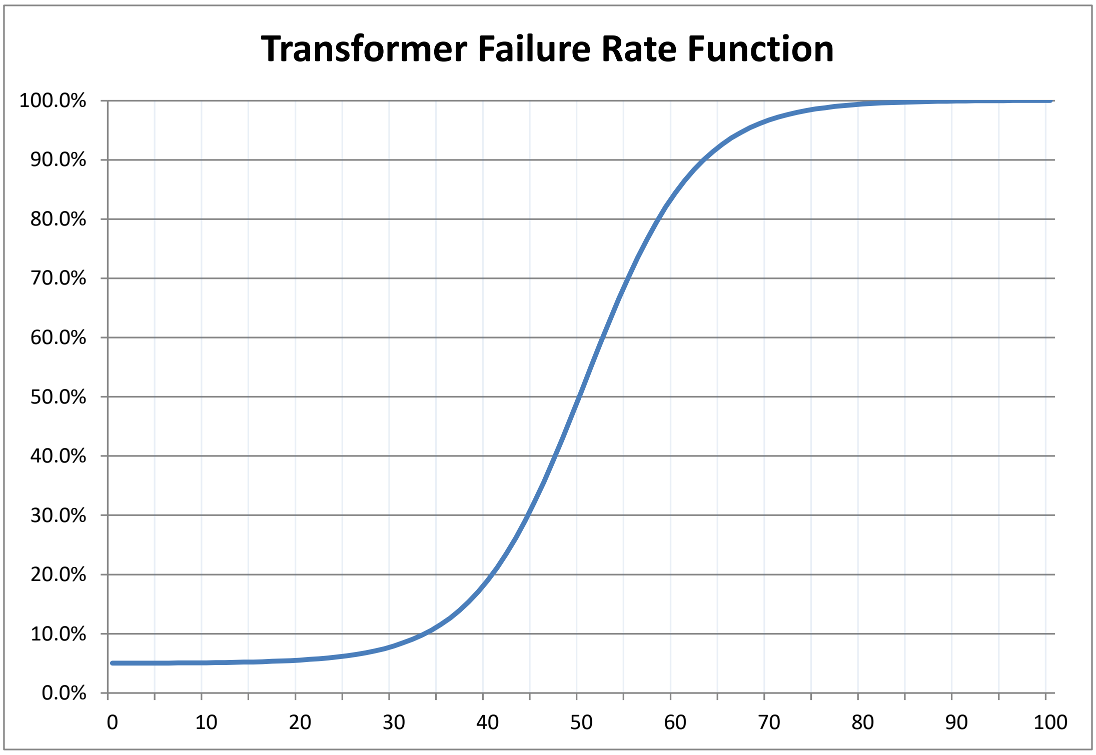
A risk model of future transformer failures based on aging has been used to calculate the cost of risk. This model utilises Perks' formula[1][2] [3].

1. In 1932 W Perks proposed a formula to closely approximate the slower rate of increase of mortality at older ages. This simple statistical model has been used for transformer failures.

Perk's formula: $$f_{(t)} = \frac{A + \alpha.e^{(\beta t)}}{1 + \mu.e^{(\beta t)}}$$

"A" is a constant set at 0.5% to take into account random events other than aging (eg lightning).

"A", "b" and "μ" are constants and "t" is years



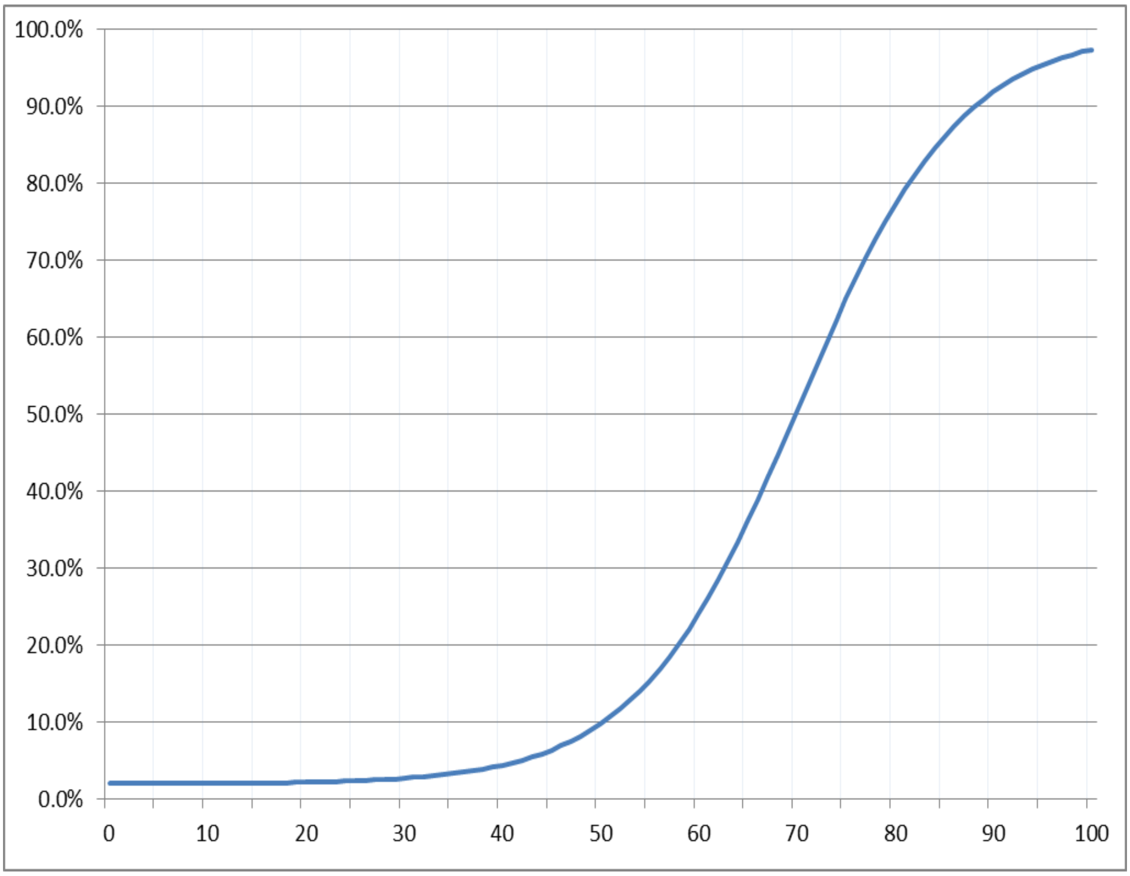
[1] William Bartley, *Analysis of Transformer Failures*, International Association of Engineering Insurers 36th Annual Conference, Stockholm, 2003

[2] Qiming Chen & David Egan, *Predicting Transformer Service Life Using Simplified Perks' Equation and Iowa Curves*, IEEE Power Engineering Society General Meeting, 2006.

[3] Qiming Chen & David Egan, *A Bayesian Method for Transformer Life Estimation Using Perks' Hazard Function*. IEEE Transactions on Power Systems Volume 21 No.4, November 2006.

2. The graph below is perceived as the most appropriate to apply to the JEN fleet of transformers because the JEN network adopts an N-1 loading philosophy, which slows the rate of paper deterioration ultimately

extending the life of a transformer. It is for this reason that Perks Transformer Failure Rate Function for a 50 year old transformer has been extended from 50 years to 70 years of age as per the graph below.



Appendix D
Network Risk Assessment Summary

Jemena

D1. NETWORK RISK ASSESSMENT SUMMARY

JEN Asset Specific (Strategic) Risk Assessment
Context statement: Replace No.2 Transformer at ZSS BD
Participants:
Workshop Date:

S/No	Business Objective	Risk Type	Risk Title (Identified Risk)	Risk Description (Including Hazard Effect)	Root Causes (Contributing Factors)	Current Controls	Adequacy of Controls	Current Consequence	Current Likelihood	Current Risk Rating	Action Plans	Target Consequence	Target Likelihood	Target Risk Rating
1	Safety	Health, Safety & Environment (JEN)	Employee and contractor injury	Explosive failure (i.e. explodes and ruptures tank, porcelain fragments and shrapnel are expelled) of transformer due to internal transformer fault or protection relay failure resulting in injury to employee or contractors. _Consequence_ : *Major* Potential life threatening injury due to equipment failure. _Likelihood_ : *Possible* Might occur at some stage in the next 5 years due to the condition of the transformers. Historically Jemena has experienced 1 event in 15 years (DVY). In Victoria there have been many events. i.e. RWN, DVY, AP, HSM.	- Assets in deteriorated condition (i.e. cellulose deteriorated, major oil leaks etc.) - Overloaded transformer under N-1 conditions - Fault (i.e. shorted turns, tap changer failure etc.) - Work practices, i.e. poor contract management, poor installation, poor maintenance (low oil therefore low dielectric strength)	- Transformer replacement as recommended in JEN PL 0042 Transformer Asset Class Strategy. - JEN Internal Standards for all construction and maintenance (including Asset Specifications). - Communicate current JEN standards. - External ESV audits influences internal compliance culture. - Collective industry experience and assessments agree that previous constructions were in accordance with the standards and good industry practice at the time. JEN continues to monitor the safety performance of these existing assets via: - Asset Inspection Program - conduct monthly operator checks and annual engineering checks and undertake corrective action. - Routine maintenance. - Condition monitoring tests (DGA, paper samples and PDC/RVM tests). - Thermal survey. - Corrective maintenance.	Adequate	Major	Possible	**High**	Replace transformers	Major	Rare	**Low**
2	Employees	Regulatory & Compliance (JEN)	ESMS compliance	Non-compliant safety performance of transformers. Duty of care to provide a safe working environment. _Consequence_ : *Severe* Isolated regulatory or policy violations/breaches. Moderate fines or penalties possible. _Likelihood_ : *Possible* Might occur at some stage in the next 5 years due to the condition of the transformers. Historically Jemena has experienced 1 event in 15 years (DVY). In Victoria there have been many events. i.e. RWN, DVY, AP, HSM.	- Assets in deteriorated condition (i.e. cellulose deteriorated, major oil leaks etc.) - Overloaded transformer under N-1 conditions - Fault (i.e. shorted turns, tap changer failure etc.) - Work practices, i.e. poor contract management, poor installation, poor maintenance (low oil therefore low dielectric strength)	- Transformer replacement as recommended in JEN PL 0042 Transformer Asset Class Strategy. - JEN Internal Standards for all construction and maintenance (including Asset Specifications). - Communicate current JEN standards. - External ESV audits influences internal compliance culture. - Collective industry experience and assessments agree that previous constructions were in accordance with the standards and good industry practice at the time. JEN continues to monitor the safety performance of these existing assets via: - Asset Inspection Program - conduct monthly operator checks and annual engineering checks and undertake corrective action. - Routine maintenance. - Condition monitoring tests (DGA, paper samples and PDC/RVM tests). - Thermal survey. - Corrective maintenance.	Adequate	Severe	Possible	**Significant**	Replace transformers	Severe	Rare	**Moderate**
3	Return on Investment	Financial (JEN)	Total cost of failure	Explosive failure resulting in damage to transformer, loss of supply to 20% of customers and subsequent recovery costs. _Consequence_ : *Major ($3.5M-$10M)* $2.5M (transformer replacement) $3M (STPIS penalty) _Likelihood_ : *Possible* Might occur at some stage in the next 5 years due to the condition of the transformers. Historically Jemena has experienced 1 event in 15 years (DVY). In Victoria there have been many events. i.e. RWN, DVY, AP, HSM.	- Assets in deteriorated condition (i.e. cellulose deteriorated, major oil leaks etc.) - Overloaded transformer under N-1 conditions - Fault (i.e. shorted turns, tap changer failure etc.) - Work practices, i.e. poor contract management, poor installation, poor maintenance (low oil therefore low dielectric strength)	- Transformer replacement as recommended in JEN PL 0042 Transformer Asset Class Strategy. - JEN Internal Standards for all construction and maintenance (including Asset Specifications). - Communicate current JEN standards. - External ESV audits influences internal compliance culture. - Collective industry experience and assessments agree that previous constructions were in accordance with the standards and good industry practice at the time. JEN continues to monitor the safety performance of these existing assets via: - Asset Inspection Program - conduct monthly operator checks and annual engineering checks and undertake corrective action. - Routine maintenance. - Condition monitoring tests (DGA, paper samples and PDC/RVM tests). - Thermal survey. - Corrective maintenance.	Adequate	Major	Possible	**High**	Replace transformers	Major	Rare	**Moderate**
4	Customers	Operational (JEN)	Loss of supply and subsequent network security	Failure of transformer resulting in loss of supply to more than 2000 customers and loss of N-1 capability resulting in a vulnerability to subsequent events. _Consequence_ : *Severe* Loss of electricity supply to >1% customers (3000) > 24 hrs (during peak demand over summer) _Likelihood_ : Possible Might occur at some stage in the next 5 years due to the condition of the transformers. Historically Jemena has experienced 1 event in 15 years (DVY). In Victoria there have been many events. i.e. RWN, DVY, AP, HSM.	- Assets in deteriorated condition (i.e. cellulose deteriorated, major oil leaks etc.) - Overloaded transformer under N-1 conditions - Fault (i.e. shorted turns, tap changer failure etc.) - Work practices, i.e. poor contract management, poor installation, poor maintenance (low oil therefore low dielectric strength)	- Transformer replacement as recommended in JEN PL 0042 Transformer Asset Class Strategy. - JEN Internal Standards for all construction and maintenance (including Asset Specifications). - Communicate current JEN standards. - External ESV audits influences internal compliance culture. - Collective industry experience and assessments agree that previous constructions were in accordance with the standards and good industry practice at the time. JEN continues to monitor the safety performance of these existing assets via: - Asset Inspection Program - conduct monthly operator checks and annual engineering checks and undertake corrective action. - Routine maintenance. - Condition monitoring tests (DGA, paper samples and PDC/RVM tests). - Thermal survey. - Corrective maintenance.	Adequate	Severe	Possible	**Significant**	Replace transformers	Severe	Rare	**Moderate**
5	Customers	Brand / Reputation / Stakeholders (JEN)	Loss of supply to >2000 customers	Failure of transformer resulting in loss of supply to large numbers of customers for extended periods - parallels cannot be made within the distribution network and rotational load shedding is implemented. Customers remain off supply until transformer is replaced. _Consequence_ : *Severe* Significant stakeholder critisicm/negativity lasting a week. _Likelihood_ : Possible Might occur at some stage in the next 5 years due to the condition of the transformers. Historically Jemena has experienced 1 event in 15 years (DVY). In Victoria there have been many events. i.e. RWN, DVY, AP, HSM.	- Assets in deteriorated condition (i.e. cellulose deteriorated, major oil leaks etc.) - Overloaded transformer under N-1 conditions - Fault (i.e. shorted turns, tap changer failure etc.) - Work practices, i.e. poor contract management, poor installation, poor maintenance (low oil therefore low dielectric strength)	- Transformer replacement as recommended in JEN PL 0042 Transformer Asset Class Strategy. - JEN Internal Standards for all construction and maintenance (including Asset Specifications). - Communicate current JEN standards. - External ESV audits influences internal compliance culture. - Collective industry experience and assessments agree that previous constructions were in accordance with the standards and good industry practice at the time. JEN continues to monitor the safety performance of these existing assets via: - Asset Inspection Program - conduct monthly operator checks and annual engineering checks and undertake corrective action. - Routine maintenance. - Condition monitoring tests (DGA, paper samples and PDC/RVM tests). - Thermal survey. - Corrective maintenance.	Adequate	Severe	Possible	**Significant**	Replace transformers	Severe	Rare	**Moderate**
6	Asset Management	Health, Safety & Environment (JEN)	Environmental issues (equipment failure)	Power transformer explodes and ruptures tank. The result is oil loss and possible fire. _Consequence_ : *Severe* Potential oil leak (possible PCB>2ppm) into environment and consequential oil fire risk. _Likelihood_ : Possible Might occur at some stage in the next 5 years due to the condition of the transformers. Historically Jemena has experienced 1 event in 15 years (DVY). In Victoria there have been many events. i.e. RWN, DVY, AP, HSM.	- Assets in deteriorated condition (i.e. cellulose deteriorated, major oil leaks etc.) - Overloaded transformer under N-1 conditions - Fault (i.e. shorted turns, tap changer failure etc.) - Work practices, i.e. poor contract management, poor installation, poor maintenance (low oil therefore low dielectric strength)	- Transformer replacement as recommended in JEN PL 0042 Transformer Asset Class Strategy. - JEN Internal Standards for all construction and maintenance (including Asset Specifications). - Communicate current JEN standards. - External ESV audits influences internal compliance culture. - Collective industry experience and assessments agree that previous constructions were in accordance with the standards and good industry practice at the time. JEN continues to monitor the safety performance of these existing assets via: - Asset Inspection Program - conduct monthly operator checks and annual engineering checks and undertake corrective action. - Routine maintenance. - Condition monitoring tests (DGA, paper samples and PDC/RVM tests). - Thermal survey. - Corrective maintenance.	Adequate	Severe	Possible	**Significant**	Replace transformers	Severe	Rare	**Moderate**

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