TS617 – Prospect ZS transformer replacement

BUSINESS CASE FOR 2017/18

Prepared by Asset Strategy and Planning

July 2017

REVIEW AND APPROVAL SCHEDULE

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CONTENTS

Endeavour Energy

1.0 EXECUTIVE SUMMARY

The purpose of this business case is to seek approval for the funding for the renewal of transformers No.1 and No.2 at Prospect Zone Substation under program TS617 during 2017/18 – 2018/19.

Assets Standards and Design (AS&D) has advised that Transformer No. 1 and Transformer No. 2 have reached the end of their life and recommended that they be replaced.

Prospect ZS was transferred from the Electricity Commission of NSW in 1960 and in 1974 it was augmented with three 15MVA transformers from Marayong ZS.

In 2011/12 Transformer No. 3, which was in very poor condition, was replaced under project TS001 – *Replacement of Prospect No. 3 Transformer*. At that time the condition of transformers No. 1 and 2 were noted as also approaching end of life and it was estimated that they would require replacement in around five years time.

This business case considers a range of options to address the transformer condition and noise issues and recommends replacing Transformer No. 1 and No. 2 with new low noise 15 MVA transformers and disposing of the old Transformer No. 1 and No. 2.

The estimated cost of the proposed works is $3.2 million in real terms and $3.3 million in nominal terms and it is expected that the project will commence in 2017/18 and will be completed in 2018/19.

A contingency amount of $0.3 million (10% of project base costs) is proposed to allow for:

- Additional works due to soil contaminated with asbestos;
- Additional work for mains construction
- Additional costs due to copper, steel and exchange rate fluctuations.

The PIPv8.3 has a provision of $6.1 million under program TS600 – *Transformer Renewals* in the period from 2017/18 to 2018/19 for these and other transformer renewal works and a total provision of $99.2 million for the period from 2017/18 to 2026/27. The funding in FY18 and FY19 is adequate for the proposed works and the future funding allocation will be re-phased in the next release of the PIP to accommodate further transformer replacement works proposed for Albion Park Zone Substation.

Accordingly, it is recommended that:

- Preliminary Gate 2 approval of $3.6 million is granted for the replacement Transformers 1 and 2 at Prospect ZS as detailed in this business case;

The capital project amount comprises a base cost of $3.3 million and a contingency allowance of $0.3 million.

2.0 INTRODUCTION

2.1 PURPOSE

The purpose of this business case is to seek approval for the funding for the renewal of transformers No. 1 and No. 2 at Prospect Zone Substation under program TS617 during 2017/18 – 2018/19. Asset Class Condition Report, Power Transformers, June 2017 from Assets Standards and Design initiated this business case. The report highlighted the poor condition of these transformers and recommended that they be replaced.

Refer APPENDIX A for detail of the Asset Class Condition Report, Power Transformers, June 2017.

2.2 BACKGROUND

Prospect Zone Substation, located on Blacktown Road Prospect is supplied at 33kV from the adjacent Blacktown Transmission Substation. Prospect ZS was transferred from the Electricity Commission of NSW in 1960 and in 1974 it was augmented with new 11kV switchgear and three 15MVA transformers relocated from Marayong ZS.

In 2011/12 Transformer No. 3, which was in very poor condition, was replaced under project TS001 – *Replacement of Prospect No. 3 Transformer*. At that time the condition of transformers No. 1 and 2 were noted as also approaching end of life and it was estimated that they would require replacement in around five years time.

TABLE 1 below shows details of the power transformers that are currently in service at Prospect ZS.

TABLE 1 : POWER TRANSFORMERS DETAILS

Transformer No.	Make	Serial No.	MVA	Voltage(kV)	Age	Tapchanger
No 1	AEI	33955	15	33/11	56	Metrovic
No 2	AEI	102076	15	33/11	52	Metrovic
No 3	Amp Control	284653	15	33/11	3	ABB

The condition of two of the three transformers is poor and assessed as being at the end of their life and therefore it is appropriate that the requirements for transformers at Prospect ZS be considered.

Refer APPENDIX B for a schematic of the supply arrangement for Prospect ZS, APPENDIX C for a single line drawing of the substation itself.

3.0 PROJECT NEED

3.1 TRANSFORMER CONDITION

The Asset Class Condition Report, Power Transformers, June 2017 indicates that transformers 1 and 2 are in very poor condition. Transformer No. 3 is three years old and in good condition.

3.1.1 END OF LIFE INDICATORS

Transformer insulation degrades with time due to moisture, heat, electrical stress and the presence of oxygen. Degraded oil insulation can be regenerated or replaced in a cost effective manner. Paper insulation however, can only be replaced by rewinding the transformer and this is generally not cost effective. As paper degrades, it loses its tensile strength. Weak paper may tear when the windings are subjected to mechanical movement during switching or short circuit conditions.

The remaining strength of paper can be measured by the degree of polymerisation (DP) of samples of paper taken from the transformer, which is an invasive process, or the DP value can be estimated by measuring the amount of Furanic compounds in the oil, which is non-invasive.

To measure the reaming tensile strength of the paper insulation a sample of the paper from the transformer winding tails collected and tested for the degree of polymerisation (DP). DP gives an indication of the length of the cellulose chain, which is proportional to tensile strength.

New transformers using paper insulation, filled with oil have a DP of approximately 1,200. As the paper degrades the DP level drops down towards zero. It is generally accepted that at a DP of around 250, the paper is too brittle to withstand the forces exerted during a switching surge or a short circuit. It is therefore considered as the theoretical end of life of the transformer.

Endeavour Energy considers transformers for replacement when their DP levels fall to 250. When DP is not available, the DP levels are estimated using the level of Furanic compounds in the oil.

Furanic compounds (such as 2FAL) are generated when the cellulose chain breaks down. Generally, Furan levels of above 2.5 ppm are indicative of poor paper strength. However, as most of the older transformers have oil leaks and require oil to be replenished. Over a period this results in a dilution of the Furan levels and therefore Furan levels may not be a reliable measure of transformer ageing and underestimate the actual loss of strength of the paper insulation .

A summary of the condition of the transformers is presented below.

3.1.2 TRANSFORMER NO. 1

Details of the condition of Transformer No. 1 are provided in TABLE 2 below.

TABLE 2 : TRANSFORMER NO. 1 CONDITION ASSESSMENT

	Condition Indicator	Units	Limits	Values	Rating	Comments
Age indicators	Furan levels	ppm	<2.5	1.0	Good	Furan values are low due to frequency of oil top ups which dilute the oil indicators, giving a result which appears to be better than it is in reality.
	Paper degree of polymerization (DP)		250	259	Very poor	DP was tested in 2013. It is expected to be much lower at this time
	CO_2/CO ratio		>7	13	Reasonable	This ratio appears to be reasonable but is unreliable due to dilution of the oil
Oil condition indicators	Oil colour classification		<5	4	Fair	This suite of indicators appear to be fair but are not reliable due to the frequency of oil top ups which distort the results, giving results which appear to be better than they are in reality.
	Myers Index			160	Very poor	
	Oil breakdown voltage	kV	>40	52	Fair	
	Water content in the oil	ppm	30 @ 40 – 60^{o}C	20	Wet	
	Oil Dielectric dissipation Factor (DDF)	mW/Var	<40 @ 90^{o}C	49	Poor	
	Acidity (Neutralisation Value)	mgKOH/g	<0.2	0.12	Good	
	Interfacial tension (IFT)	mN/m	>18	19	Fair	
	Oil conductivity	pS/m	<5.0	7.79	Fair	
Winding and bushing indicators	Winding dielectric loss angle (DLA)	mR	<4 – good 4 – 7 - reasonable >7 – Poor	11.25	Very poor	
	Bushing DLA	mR	<4 – good 4 – 7 - reasonable >7 – Poor	-	-	No test results available
	Polarization index (PI)		>2 - good 1.25 – 2.0 – reasonable <1.25 - poor	1.08	Poor	
	Insulation resistance (IR)	MΩ	>210 (HV) >71 (LV)	880 503	Fair Fair	

	Condition Indicator	Units	Limits	Values	Rating	Comments
	Winding differential resistance	Ω	<0.02	0.004	Fair	
	Dissolved gas levels		various		Good	DGA levels appear to be good but are unreliable due to numerous oil top ups which dilute the oil markers

An image of Transformer No. 1 is shown in FIGURE 1 below.

FIGURE 1 : TRANSFORMER NO. 1

3.1.2.1 TRANSFORMER NO. 1 CONDITION SUMMARY

Although a number of condition indicators appear to be fair to poor, these indicators underestimate the condition due to dilution which is caused by the regular oil top ups that have been carried out.

This transformer is in very poor condition due to the very low DP level, which is exacerbated due to oil leaks and moisture ingress and makes the transformer susceptible to internal failure if subjected to a through fault event.

3.1.3 TRANSFORMER NO. 2

Transformer No. 2 is 52 years old and is the same design as Transformer No. 1. Further detail of the condition of Transformer No. 2 is provided in TABLE 3 below.

TABLE 3 : TRANSFORMER NO. 2 CONDITION ASSESSMENT

	Condition Indicator	Units	Limits	Values	Rating	Comments
Age indicators	Furan levels	ppm	<2.5	0.5	Fair	Furan values are low due to frequency of oil top ups which dilute the oil indicators, giving a result which appears to be better than it is in reality.
	Paper degree of polymerization (DP)		250	363	Poor	The DP was tested in 2009 when this transformer was 44 years old and in better condition. Since then its condition has deteriorated and the DP levels are expected to be very poor
	CO_2/CO ratio		>7	16	Reasonable	This suite of indicators appear to be fair but are not reliable due to the frequency of oil top ups which distort the results, giving results which appear to be better than they are in reality.
Oil condition indicators	Oil colour classification		<5	4	Fair	
	Myers Index			526	Fair	
	Oil breakdown voltage	kV	>40	42	Poor	
	Water content in the oil	ppm	30 @ 40 – 60^{o}C	23	Wet	
	Oil Dielectric dissipation Factor (DDF)	mW/Var	<40 @ 90^{o}C	43	Poor	
	Acidity (Neutralisation Value)	mgKOH/g	<0.2	0.09	Good	
	Interfacial tension (IFT)	mN/m	>18	19.5	Good	
	Oil conductivity	pS/m	<5.0	6.74	Poor	
Winding and bushing indicators	Winding dielectric loss angle (DLA)	mR	<4 – good 4 – 7 - reasonable >7 – Poor	3.9	Reasonable	
	Bushing DLA	mR	<4 – good 4 – 7 - reasonable >7 – Poor	-	-	No test results
	Polarization index (PI)		>2 - good 1.25 – 2.0 – reasonable <1.25 - poor	1.21	Very poor	
	Insulation resistance (IR)	MΩ	>210 (HV) >71(LV)	570 532	Fair Fair	
	Winding differential resistance	Ω	<0.02	0.01	Fair	
	Dissolved gas levels		various		good	DGA levels appear to be good but are unreliable due to numerous oil top ups which dilute the oil markers

An image of Transformer No. 2 is shown in FIGURE 2 below.

FIGURE 2 : TRANSFORMER NO. 2

3.1.3.1 TRANSFORMER NO. 2 CONDITION SUMMARY

Although a number of condition indicators appear to be fair to poor, these indicators underestimate the condition due to dilution which is caused by the regular oil top ups that have been carried out.

Transformer No. 2 is in poor condition and its DP level is expected to be below 250 as its condition has deteriorated since 2009 when the DP level of 363 was measured.

This transformer is in very poor condition due to the very low DP level, which is exacerbated due to oil leaks and moisture ingress and makes the transformer susceptible to internal failure if subjected to a through fault event.

3.2 TRANSFORMER REPLACEMENT METHODOLOGY

Endeavour Energy uses a transformer replacement methodology to plan for transformer replacements. This methodology prioritises power transformer replacements based on condition and their criticality in the network.

Transformer replacements are prioritised as high priority, medium priority, low priority and those not requiring replacement due to their condition are ranked replacement priority not required.

Transformer condition is ranked from one to 10 with one being in good condition and 10 being in very poor condition.

A transformer's criticality number ranges from one to 15 with 1 being lowest critical service in the network and 15 being highest. A combination of the following aspects is used to determine the criticality:

- Load type (domestic, industrial, and commercial mix) ;
- Substation type (zone or transmission): and

- Network load at risk (extent to which the firm capacity at a substation is exceeded).

Given Endeavour Energy's network and the loads that are supplied, the criticality range for the fleet of power transformers usually resides within the four to 11 range of criticality.

The condition of the entire fleet of power transformers is presented in TABLE 4 below.

The numbers inside the matrix reflect the number of transformers that are in this category. E.g. in the Condition rating = 6 and the Criticality range = 8, there are 4 units at this time. As the condition of transformers deteriorate more units will move from regions of lower priority to higher priority in the replacement matrix.

TABLE 4 : TRANSFORMER REPLACEMENT PRIORITY MATRIX

		Criticality													Total
		3	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	
Condition Rating	**1**		12	40	0	0	2	0	0	0					54
	2		61	49	15	15	19	0	0	7					166
	3		0	2	0	0	0	0	0	0					2
	4		1	0	3	0	0	0	0	0					4
	5		6	7	5	9	4	0	2	0					33
	6		27	21	10	5	4	2	1	0					70
	7		37	21	13	5	7	0	0						83
	8		15	5	3	2	10	0	1						36
	9		2	1	1	0	0	0	1						5
	10		0	0	1[1]	0	0	0	0						1
Total		0	161	146	51	36	46	2	5	7	0	0	0	0	454

Note [1] – This is the old Nepean Transformer No. 3, which is scheduled for disposal in 2017/18.

TABLE 5 below shows the quantities that are in the power transformer replacement program.

TABLE 5 : PLANNED REPLACEMENT QUANTITIES

Replacement Priority	Quantity of transformers	% of population
High Priority	2[2]	0.44%
Medium Priority	15	3.30%
Low Priority	71	15.64%
Quantity in replacement prioritisation plan	88	19.38%
Quantity not in replacement plan	366	80.62%
Total units	454	100%

Note [2] – Nepean TRANSFORMER 3 which is surplus to requirements and will be removed in 2017/18 and Camellia TRANSFORMER 1 which will be replaced in 2017/18 under project TS608 - *Camellia TS Transformer replacement and 33kV busbar rearrangement.*

Ranking of Prospect power transformers in the replacement matrix are shown in TABLE 6 below.

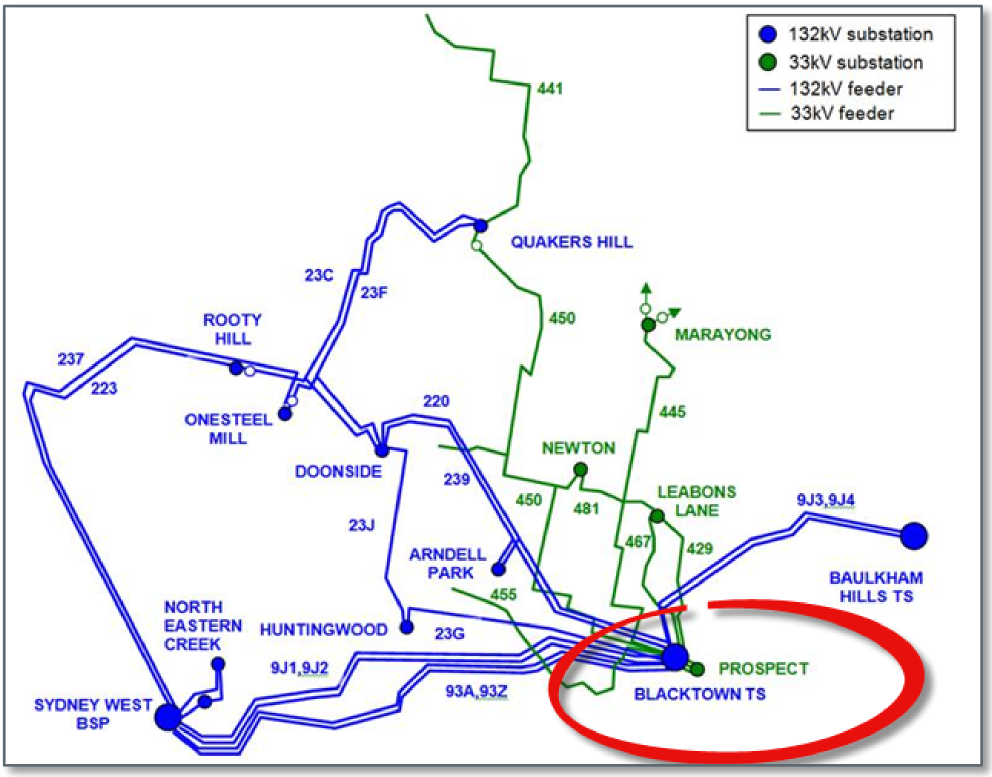
TABLE 6 : PROSPECT TRANSFORMERS IN REPLACEMENT MATRIX

		Criticality												
		3	4	5	6	7	8	9	10	11	12	13	14	15
Condition Rating	1				T3									
	2													
	3													
	4													
	5													
	6													
	7													
	8				T2									
	9				T1									
	10													

3.3 NETWORK NEED

Prospect ZS is supplied at 33kV from the adjacent Blacktown TS as shown in FIGURE 3 below.

FIGURE 3 : SUPPLY ARRANGEMENT TO PROSPECT ZS



3.3.1 DEMAND FORECAST

The summer peak demand forecast for Prospect ZS is 30MVA (with a 50% probability of being exceeded) as shown in TABLE 7 below.

TABLE 8 shows that the winter peak demand is forecast to reach 24MVA.

Capacity Planning has advised that an N-1 level of supply security is required and due to the flat load forecast, three 15 MVA transformers are required at Prospect ZS to provide a firm of 30MVA for the foreseeable future.

TABLE 7 : PROSPECT ZS SUMMER DEMAND FORECAST

Location		Actual						Forecast									
		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Actual	**MVA**	**27.9**	**22.3**	**30.0**	**25.3**	**25.4**	**29.7**										
Prospect	MW	28.5	28.4	28.7	28.2	27.9	28.7	29.9	31.8	31.7	31.6	31.6	31.5	31.4	31.4	31.3	31.4
	MVAr	4.6	1.8	6.7	2.0	2.2	10.3	5.7	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
10% POE	**MVA**	**28.9**	**28.5**	**29.5**	**28.3**	**28.0**	**30.5**	**30.4**	**32.4**	**32.3**	**32.2**	**32.1**	**32.1**	**32.0**	**31.9**	**31.9**	**32.0**
	PF	0.987	0.998	0.974	0.997	0.997	0.941	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982
	MW	26.0	26.0	26.2	25.7	25.5	26.3	27.5	29.4	29.3	29.3	29.2	29.1	29.1	29.0	29.0	29.0
	MVAr	4.2	1.6	6.1	1.8	2.0	9.5	5.2	5.6	5.6	5.6	5.6	5.5	5.5	5.5	5.5	5.5
50% POE	**MVA**	**26.4**	**26.0**	**26.9**	**25.8**	**25.5**	**28.0**	**28.0**	**29.9**	**29.9**	**29.8**	**29.7**	**29.6**	**29.6**	**29.5**	**29.5**	**29.5**
	PF	0.987	0.998	0.974	0.997	0.997	0.941	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982	0.982

TABLE 8 : PROSPECT ZS WINTER DEMAND FORECAST

Location		Actual						Forecast									
		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Actual	**MVA**	**22.8**	**21.5**	**22.0**	**22.2**	**23.8**	**22.0**										
Prospect	MW	21.7	21.0	21.4	21.7	22.5	21.6	24.2	24.6	24.6	24.5	24.5	24.5	24.5	24.5	24.5	24.7
	MVAr	2.6	2.2	1.6	1.5	1.3	0.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
10% POE	**MVA**	**21.8**	**21.2**	**21.4**	**21.8**	**22.5**	**21.6**	**24.3**	**24.7**	**24.6**	**24.6**	**24.6**	**24.6**	**24.6**	**24.6**	**24.6**	**24.7**
	PF	0.993	0.995	0.997	0.998	0.998	1.000	0.997	0.997	0.997	0.997	0.997	0.997	0.997	0.997	0.997	0.997
	MW	21.0	20.6	20.9	21.0	21.8	21.0	23.6	24.0	23.9	23.9	23.9	23.9	23.8	23.9	23.9	24.0
	MVAr	2.5	2.1	1.6	1.5	1.3	0.4	1.9	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
50% POE	**MVA**	**21.2**	**20.7**	**21.0**	**21.0**	**21.9**	**21.0**	**23.7**	**24.0**	**24.0**	**24.0**	**24.0**	**23.9**	**23.9**	**23.9**	**23.9**	**24.1**
	PF	0.993	0.995	0.997	0.998	0.998	1.000	0.997	0.997	0.997	0.997	0.997	0.997	0.997	0.997	0.997	0.997

3.4 OTHER NEEDS

3.4.1 NOISE ISSUES

Prospect ZS in a residential area and there are residences and a school in close proximity of the substation. Although, there has not been any noise complaint, in 2011, when Transformer No. 3 was replaced, a noise survey was carried out to assess the environmental noise impact of the substation equipment on the premises that are adjacent to the substation. The survey found that the noise emission from the substation was above the recommended noise limits and recommended that noise controls measures be carried out to ensure compliance.

Noise guidelines from the NSW Industrial Noise Policy (EPA, 2000) [1] are used to assess the noise emanating from Endeavour Energy's substations. This noise policy is aimed at assessing noise from "scheduled" premises under the Protection of Environment Act 1997 [2]. Endeavour Energy substations are not "scheduled" premises. However, in the absence of policy specific to Endeavour Energy's zone substations, the guidelines under the NSW Industrial Noise Policy are used to assess whether a "reasonable person" is likely to find the noise offensive, and thus warrant investment to reduce the noise levels.

In 2011 it was resolved that the replacement transformers at Prospect ZS would be low noise units to ensure compliance to the NSW Industrial Noise Policy would be achieved as the transformers were replaced over time.

Accordingly, it is proposed that any replacement transformer be low noise designs.

Refer APPENDIX E for details of the noise report.

3.4.2 FIRE PROTECTION

Currently there are inadequate fire separation distances or firewalls between Transformers 1 and 2 and between these transformers and the control building, that houses the 11kV switchgear. As both transformers No.1 and No.2 are in poor condition, they are likely to fail when subjected to a through fault event. If the failure results in a transformer fire, the fire is likely to destroy the adjacent transformer and the control building.

Under this scenario, it is likely that the substation will be out of commission for an extended period with subsequent supply security and reliability risks.

Accordingly, it is proposed that fire protection measures are under taken at this site as part of any major renewal works.

3.4.3 RISK ASSESSMENT

Endeavour Energy's Risk Management procedure GRM 0003 covers the business risk across the company. The framework outlined in the GRM 0003 has been followed in this risk assessment of Prospect ZS transformers shown in TABLE 9 below. However, the impact criteria have been focused to this specific site.

TABLE 9 : RISK ASSESSMENT

Risk	Likelihood	Impact	Business Risk	Comment	Treatment of risk
Transformer fails and catches fire	Possible (C)	Moderate (3)	High (C3)	As both T1 and T2 are in very poor condition, they are likely to fail if subjected to a through fault event. If the failure results in a transformer fire, the fire is likely to destroy the adjacent transformer and the control building. The STPIS impact of a one-hour outage at Prospect ZS is $670,000.	Replace both transformers with new units and install four firewalls to maintain supply security and to reduce the risk to low. (E3)
Failure of two transformers during a system fault	Likely (B)	Moderate (3)	High (B3)	As both T1 and T2 are operated in parallel, and due to their very weak paper strength, both transformers are likely to fail in the event of a close up system fault. The substation load can be taken up by the neighbouring zones substations for limited periods only but not during the peak summer demand.	Replace both transformers with new units to maintain supply security and to reduce the risk to low. (E3)
Failure of one transformer during a system fault and the subsequent failure of the second transformer before the failed transformer is replaced	Likely (B)	Moderate (3)	High (B3)	It will normally take about a month to replace a failed transformer with a system spare and this leaves the substation at risk during this period.	Replace both transformers with new units to maintain supply security and to reduce the risk to low. (E3)
Failure of one transformer during a system fault	Likely (B)	Minor (2)	Medium (B2)	Reduced supply security to customers with one transformer out for a prolonged period.	Replace both transformers with new units to reduce the risk to low. (E2)
Noise complaints	Possible (C)	Minor (2)	Medium (C2)	Noise emissions from these transformers are above the limits and therefore noise complaints may become an issue in the future.	Replacement transformers to be low noise units. (E2)

3.4.4 CONCLUSIONS

Transformers 1 and 2 are not fit for continued service and at a high risk of failure. Therefore, they require replacement in the short term.

Transformer 3 is in new condition and should be retained in service for the long term

4.0 INVESTMENT OPTIONS

The following options for the transformers at Prospect ZS have been considered:

1. Do nothing;
2. Refurbish Transformer No. 1 and No.2;
3. Replace Transformer No. 1 and No.2;

4.1 OPTION 1 - DO NOTHING

This option includes not replacing Transformers 1 and 2 at this time, and to continue to operate the substation with these transformers in their present condition.

Transformers 1 and 2 are in very poor condition and the risk of failure of either of them is high. If one transformer fails catastrophically and causes a fire, the fire could damage the adjacent transformer and control building, (which incorporates the 11kV switchgear), as there are no firewalls or adequate fire separation (distances) between either of the transformers and the building. This event would cause a significant outage of the substation.

Therefore, Do Nothing presents an unacceptable level of risk and is rejected as not being a solution to the needs at the substation.

4.2 OPTION 2 - REFURBISHMENT

This option includes refurbishing or rebuilding transformers 1 and 2.

However, refurbishment of transformers of this age and condition is not considered practicable due to:

- The very poor condition of these transformers giving rise to unreliable results of the refurbishment;
- The poor condition of radiators which will require their replacement as it is not cost effective to repair them;
- The lack of available spare parts for these old tap-changers. Consequently the tapchanger will require replacement with a new type and this may also require modification of the main tank and conservator;
- The likelihood of lead paint inside the tank causing increased costs; and
- The transformer will be out of service for an extended period leaving the substation with a reduced level of supply security for the duration.

Therefore, refurbishment of transformers of this age and condition is considered to present excessive risk and not be commercially viable and is rejected as not being a solution to the needs at the substation.

4.3 OPTION 3 - REPLACE TWO TRANSFORMERS

This option is to replace the existing Transformer No. 1 and No. 2 with low noise 15MVA transformers in new bunds that are fitted with firewalls. Also included in this option is the replacement of the 33kV cables from Blacktown TS, replacement of the 11kV cables to the 11kV switch room, the relocation of a lightning mast and disposal of the redundant transformers.

The cost of this option is $3.2 million.

Refer FIGURE 4 for the arrangement of the existing transformers and lightning mast and

FIGURE 5 for the proposed new arrangement, which includes the firewalls and the relocated lightning mast.

FIGURE 4 : EXISTING TRANSFORMER ARRANGEMENT

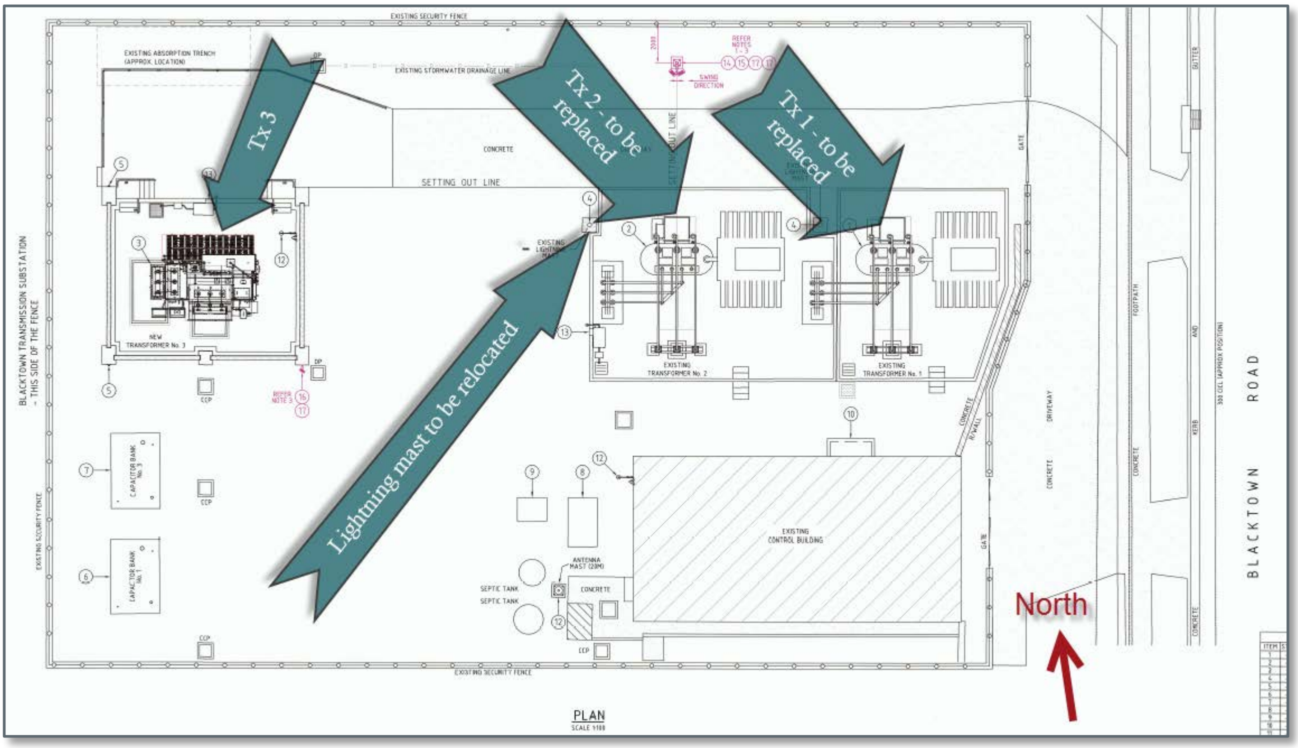
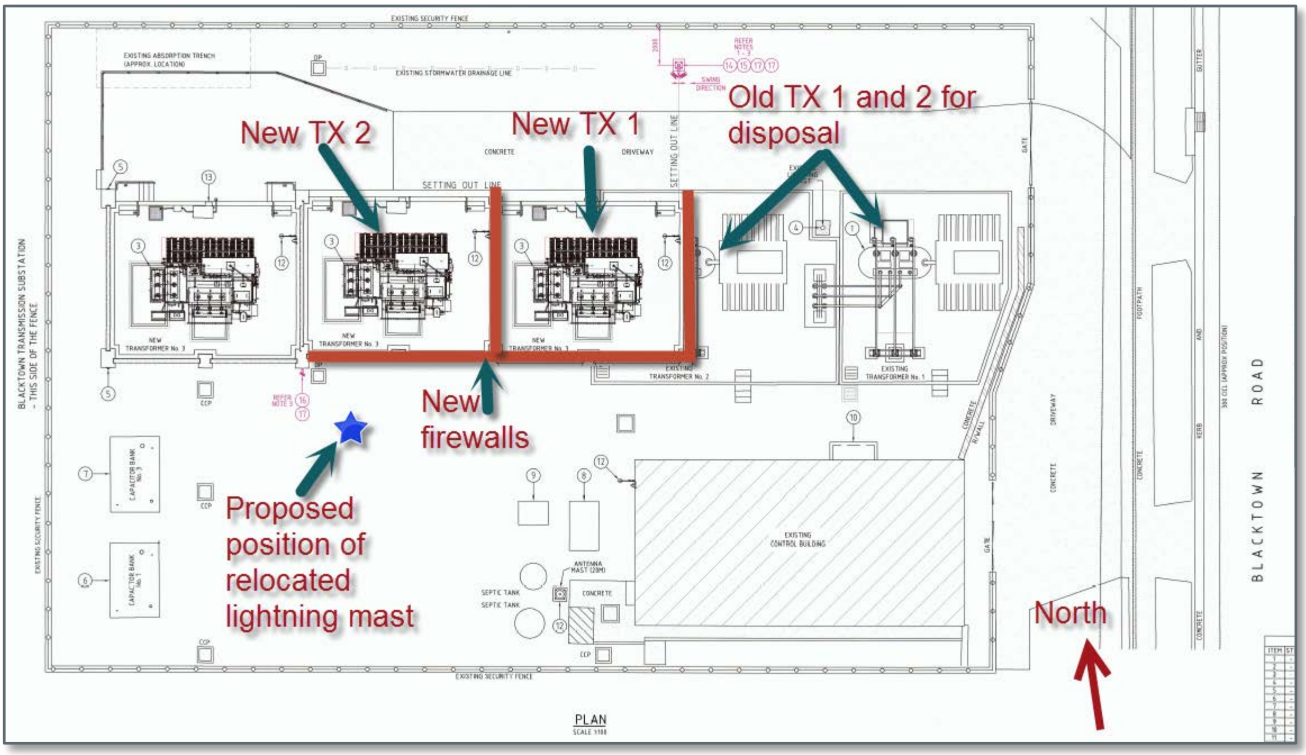


FIGURE 5 : PROPOSED TRANSFORMER ARRANGEMENT



4.4 RECOMMENDED OPTION

Given that both Transformer No. 1 and No. 2 are in poor condition and at end of life, they have to be replaced to satisfy the N-1 supply security requirements at this site. Therefore, Option 1 - *Do Nothing* is not a suitable option.

Option 2, the refurbishment option is considered to be neither dependable nor cost effective and is considered to present excessive risk and therefore it is rejected as not being a solution to the needs at the substation.

Option 3, which proposes to replace the two transformers in poor condition with two new low noise 15MVA transformers, is the only option that will ensure that the on-going serviceability and supply security. Therefore, Option 3 is recommended as the preferred option.

5.0 PROJECT SCOPE

5.1 PROJECT WORKS SCOPE

The proposed project scope includes:

1. Construction of a new transformer bund adjacent to Transformer No. 3;
2. Installation of firewalls on the eastern and southern sides of the new Transformer No. 2;
3. The purchase and installation of a new low noise 15MVA transformer in this bund;
4. Installation and connection of new 33kV cables from Blacktown TS to this new Transformer No. 2.
5. Converting the 11kV indoor switchboard's existing pitch filled cable termination to an air termination;
6. Installation and connection of 11kV cables and control cables from the new Transformer No. 2 to the switchboard and control panels at Prospect ZS;
7. Decommissioning the old Transformer No. 2 and commissioning the new Transformer No. 2 in its place;
8. Disposal of the old Transformer No. 2;
9. Carry out a lightning study for the new substation layout for the purpose of relocating the lightning mast that is adjacent to the western end of the bund for the old Transformer No. 2;
10. Construction of a new transformer bund adjacent to the new Transformer No. 2 for the new Transformer No. 1;
11. Installation of firewalls on the eastern and southern sides of the new Transformer No. 1;
12. The purchase and installation of a new low noise 15MVA transformer in this bund;
13. Installation and connection of 33kV cables from Blacktown TS to new Transformer No. 1;
14. Modification of the transformer Feeder No. 1's 11kV cable box to an air termination;
15. Installation and connection of 11kV cables and control cables from new Transformer No. 1 to the switchboard and control panel at Prospect ZS;
16. Decommissioning of the existing old Transformer No. 1 and commissioning of the new Transformer No. 1
17. Disposal of the old Transformer No. 1;

18. Demolishing the bunds and plinths of the old Transformer No. 1 and Transformer No.2 to make the yard safe;

19. Appling a layer of crushed rock over the demolished bund areas.

6.0 COST ESTIMATE

The estimated costs for these works, shown in TABLE 10 below, were provided by Assets Standards and Design.

TABLE 10 : COST ESTIMATE (REAL 2017/18 $)

Item	Costs ($)
Planning and development	**50,000**
Substation design	**60,000**
Civil works – two transformer bunds and footings	**600,000**
Civil works – four firewalls	**300,000**
Purchase, installation, testing and commissioning of two new 33/11 kV 15 MVA low noise transformers	**1,540,000**
Electrical and protection works to connect and test new transformers	**100,000**
Mains works – 33 and 11 kV cabling	**360,000**
11kV switchgear air-box modifications	**50,000**
Lightning study for the relocation of a lightning mast and its relocation	**30,000**
Disposal of old transformers and demolition of old bunds and plinths	**60,000**
Project management	**90,000**
Project base costs	**3,240,000**

6.1 CONTINGENCY

TABLE 11 below shows details of the contingency amount, which equates to approximately 10% of the project direct costs.

TABLE 11 : CONTINGENCY (REAL 2017/18 $)

Item	Costs ($)
Additional works due to contaminated soil	**260,000**
Additional work for mains construction	**35,000**
Additional costs due to copper, steel and exchange rate fluctuations	**15,000**
Total contingency	**310,000**

7.0 FUNDING PROVISION

The PIPv8.3 has a provision of $6.10 million under program TS600 – *Transformer Renewals* in FY18 to FY19 for these and other transformer renewal works and a total provision of $99.2 million for the period from FY18 to FY27. The funding in FY18 and FY19 is adequate for the proposed works and the future funding allocation will be re-phased in the next release of the PIP to accommodate further transformer replacement proposed for Albion Park ZS.

A cash flow representing the expected expenditure spread and including contingency for the expenditure is shown in TABLE 12 below.

TABLE 12 – PROJECT EXPENDITURE SPREAD

Estimated Cost	2017/18	2018/19	Total
PIP 8.3 ($ nominal)	2,000,000	4,100,000	**6,100,000**

Project base costs (real 2017/18 $)	1,000,000	2,240,000	**3,240,000**
Project costs ($ nominal)	1,000,000	2,300,000	**3,300,000**
Contingency ($ nominal)	100,000	220,000	**320,000**
Total project costs ($)	1,100,000	2,520,000	**3,620,000**

8.0 RECOMMENDATIONS

It is recommended that:

- Preliminary Gate 2 approval of $3.6 million is granted for the replacement Transformers 1 and 2 at Prospect ZS as detailed in this business case;

The capital project amount comprises a base cost of $3.3 million and a contingency allowance of $0.3 million.

9.0 REFERENCES

1. NSW Industrial Noise Policy – NSW Environment Protection Authority (EPA 2000).
2. Protection of the Environment Operations Act 1997.

10.0 APPENDICES

APPENDIX A : ASSET CLASS CONDITION POWER TRANSFORMERS

APPENDIX B : PROSPECT ZS SUPPLY ARRANGEMENTS

APPENDIX C : PROSPECT ZS SINGLE LINE DRAWING

APPENDIX D : DETAIL COST ESTIMATE

APPENDIX E : NOISE REPORT

APPENDIX A : ASSET CLASS CONDITION POWER TRANSFORMERS

#1000

Asset Class Condition

Asset Class: Power Transformers

Health Status: June 2017

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Version

Version	Date	Author	Content
0.8	9/6/17	Tay	Release for edit / review
0.9	14/6/17	Crisafulli	Last edits prior to completion
1.0	16/6/17	Tay / Crisafulli	Release for BM review
1.1	26/6/17	Crisafulli	Comments addressed; additional definitions added; additional support of statistics provided

Endorsement

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Contents

Abbreviations

A	Amp
BSP	Bulk supply point
CLF	Central logistics facility
DBDS	Dibenzyl disulphide, a reactive sulphuric compound present in some transformer oils
DBPC	2,6-di-tert-butyl-paracresol, a synthetic oil inhibitor
DBP	2,6-di-tert-butyl-phenol, a synthetic oil inhibitor
DDF	Dielectric dissipation factor
DGA	Dissolved gas analysis
DLA	Dielectric loss angle
DNSP	Distribution network service provider
DP	Degree of polymerisation of the paper insulation
FSC	Field service centre
IR	Insulation resistance
OLTC	On-load tap changer
PD	Partial discharge
PDC / FDS	Polarisation de-polarisation current – frequency domain spectrometry
PI	Polarisation index
SARP	Strategic asset renewal plan
TNSP	Transmission network service provider (TransGrid)
TS	Transmission substation
TX	Transformer
V	Volt
ZS	Zone substation

Definitions

Guide asset life	Also known as design asset life; 45 years, based generally on the standard asset lives in accordance with NSW Treasury – Valuation of Electricity Network Assets. From Company Policy 9.2.5. – Network Asset Design.
Planned asset lifetime	50 years; the age considered in financial modelling as the appropriate age for power transformers based on industry experience.
EOL1	End-of-life category 1: transformers considered beyond a minimum condition considered appropriate for continued service in the network
EOL2	Nearing end of life category: transformers considered no longer meeting a minimum health and are at heightened risk of failure and require planned replacement in the short to medium term
M&A	Monitor and assess category: units showing early deterioration of health or units beyond a given age that are expected to be of poor condition but may not show signs of poor health that require particular focus to gain confidence in their health and future decisions.

1.0 Executive summary

There are currently 454 in-service power transformers in the network. The average age for an in-service power transformer is 24.8 years. The age profile is characterised by three major investment cycles – the most recent between 2000 and 2014 (228 units); between 1976 and 1988 (85 units) and between 1963 and 1974 (93 units). There are also 39 units that have reached or surpassed the end of the planned asset lifetime.

The average health of the fleet is shown in the figure below by age group. The boxes indicate the standard deviation of the age group health (± 1 σ) and the line indicates the median health of the age group. The whiskers indicate the highest and lowest health transformers of the age group. While age group is statistically reflective of health, the older age groups have proactive works to reduce the number of poor-health transformers through replacement programs.

Table 1 – Power transformer asset condition profile

% of assets	5%	10%	50%	90%	95%
Asset health index	59%	79%	99%	100%	100%

The main risk to power transformers is the degradation of the insulating mediums within the transformer, which can cause electrical fault damage to internal components; or mechanical damage from the physical movement that result from an electrical fault. The two types of insulation in transformers are paper insulation of the windings and mineral oil in the main tank. Mineral oil deteriorates from exposure to heat, moisture and air. Similarly, paper insulation also degrades due to exposure to heat and moisture. Therefore, the risk of oil leaks, moisture ingress and overheating of the transformer are considered major risks to the asset health.

In the last 10 years, there have been 13 power transformer failures in the Endeavour Energy network with a median age of the unit at time of failure of 44 years. 30% of the failed units were large power transformers used at Transmission Substations which are over-represented on a per unit basis.

There are emerging risks in the high proportion of ageing 60MVA and 120MVA power transformers, particularly those inherited from the Electricity Commission of NSW transmission substation sites. Transmission Substation power transformers are of high significance to the reliable supply of electricity to customers. The power transformer at the transmission substation therefore is intrinsic to the supply security of all the zone substations and high voltage customers connected to the transmission substation. Further, given the nature of lower manufacturing capability, longer lead times, cost and staging impacts, such power transformers require particular focus so that targeted actions such as mid-life refurbishment, oil leak repairs and oil regeneration / replacement will maintain the health of a transformer.

There is a short to medium term need to address the large power transformer units not only on condition but also due to their criticality in supplying power to zone substations downstream. This is a significant financial investment and units are prioritised according to asset condition, site criticality and condition of units on the same site.

The current health assessment index and risk rating for the fleet of transformers outlines 3 target groups for which remedial actions can be undertaken to maintain the health of the transformer, or to schedule for replacement. These groups, as defined in Section 4.2, are the EOL1 End-of-life group (1 transformer); EOL2 Nearing end of effective life (33 transformers) and potential risk - M&A monitor & assess (21 transformers). There are additional strategies to continue to achieve ongoing asset performance or address emerging risks particularly around the management of insulating oil quality as well as leaking transformer risks.

A summary of the power transformer asset class condition assessment recommendations is as follows:

Table 2 - Recommended actions for the power transformer asset class

Criteria / Strategy	Recommendation
End of life (EOL1) (Section 4.2.1)	• 1 transformer, Nepean TX 3, prioritised for replacement in 2017/18
Nearing end of life (EOL2) (Section 4.2.1)	• 32 transformers in the EOL2 group • 17 to be considered for replacement • 7 units were identified to have DP tests carried out in FY 2017/18 • 9 units will be monitored for any further deterioration and assessed further in 17/18 FY; if deterioration occurs, the units will be programmed for replacement.
Potential risk – monitor and assess (M&A) (Section 4.2.1)	• 3 transformers that are scheduled for DP testing in 2017/18 • 18 to be monitored for change in condition and elevation to EOL2 if health score deteriorates.
Oil leaks and refurbishments (Section 4.2.2)	• 11 transformers to be refurbished to repair oil leaks and maintain transformer health
Poor oil quality – oil regeneration or replacement (Section 4.2.3)	• 6 transformers identified for oil regeneration or replacement
DBDS risk - oil passivation (Section 4.2.4)	• 15 transformers to be dosed with oil passivators to treat DBDS risk

2.0 Introduction

2.1 Scope of this document

This report provides a current asset class condition summary of power transformers in the Endeavour Energy network and recommendations for the ongoing asset management of the associated fleet.

The asset health index provides a quantitative indication of the overall asset fleet and key asset for consideration of replacement. Additionally, particular individual determining factors are also assessed outside the health index to determine appropriate refurbishment or renewal strategies for assets based on defined limits. Namely, this report will provide:

- prioritised asset replacements based on known asset health
- further investigation on assets with expected poor health but not indicative in the health index
- assets identified for non-routine repair or refurbishment
- details regarding the monitoring of assets showing deteriorating trends in health outside the expected health deterioration rate

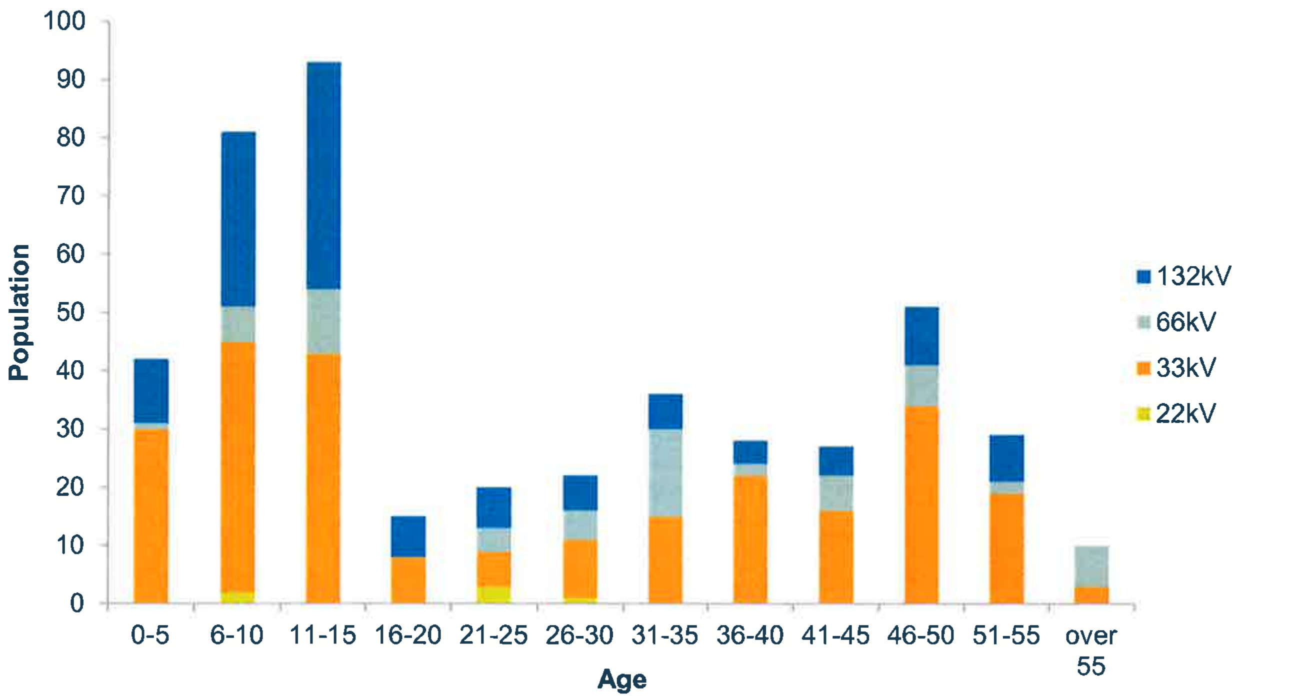
This document also identifies potential deficiencies and future work in obtaining more reliable health data to continually improvement decision frameworks for the asset fleet.

2.2 Asset class profile

Power transformers can be classified by voltage, size and age. A summary of the current in-service fleet by primary voltage and age is provided below.

Table 3 – Asset class profile by age and primary voltage

Power Transformers	0-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	over 55
22kV	0	2	0	0	3	1	0	0	0	0	0	0
33kV	30	43	43	8	6	10	15	22	16	34	19	3
66kV	1	6	11	0	4	5	15	2	6	7	2	7
132kV	11	30	39	7	7	6	6	4	5	10	8	0



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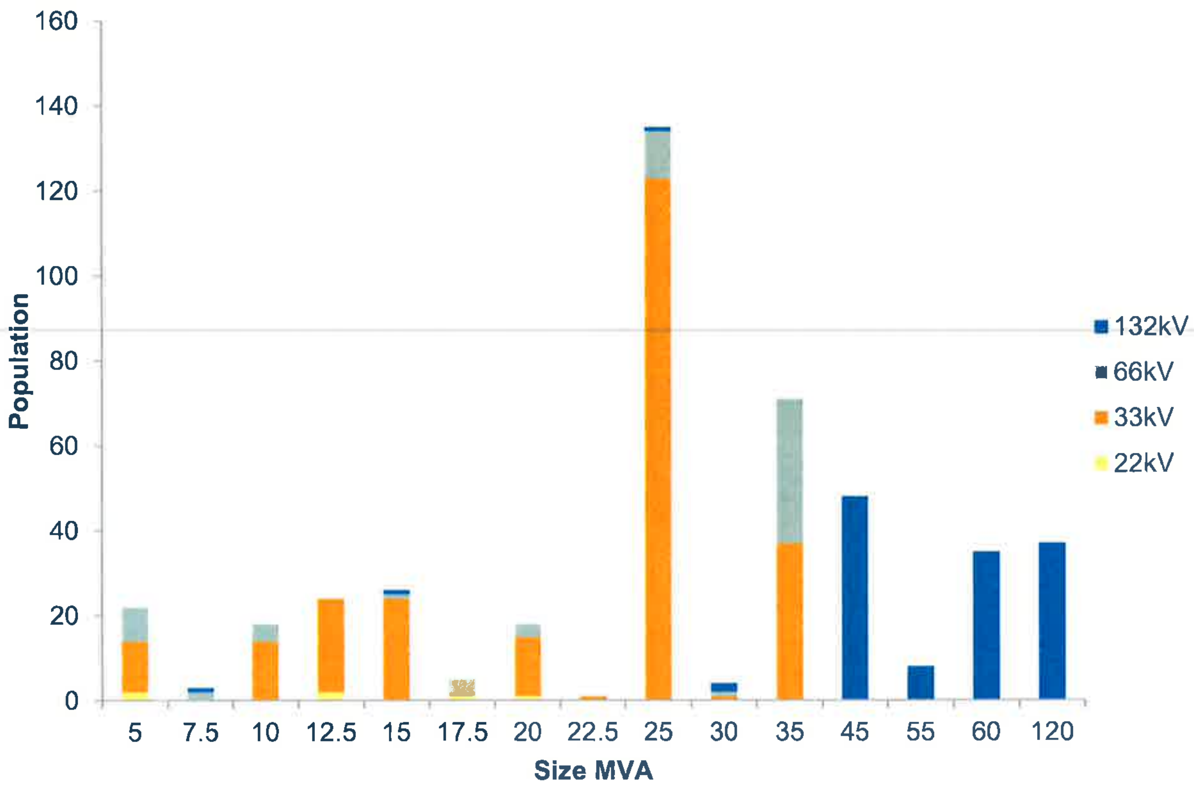
The average age for an in-service power transformer is 24.8 years. The age profile is characterised by three major investment cycles – the most recent between 2000 and 2014 (228 units); between 1976 and 1988 (85 units) and between 1963 and 1974 (93 units). There are also 39 units that are >50 years old and reaching the end of the planned asset lifetime.

Note that, due to the lack of nameplate information for some older transformers and also the use and movement of spare transformers, the commissioning date and/or profile date (e.g. the estimated manufacturing date of transformer) is used where there is no manufacturing date recorded in Ellipse.

Transformer size is important as it is the major factor in the estimated cost of a transformer as well as its potential consequential loss of load if subject to failure. The most prevalent transformer size is 25 MVA (135 units), as well as 71 units rated at 35 MVA and 48 units rated at 45 MVA; these units form the bulk of the transformer population in zone substations. There are 72 units sized at 60 MVA and 120 MVA and these are used in transmission substations to distribute electricity from the TNSP BSPs to zone substations. Also, there are a total of 116 units rated at 20MVA and below.

Table 4 - Asset class by size MVA and primary voltage



2.3 Input / output summary and process overview

The conditional assessment of power transformers was generated in accordance with SMI161 – Asset Health Index which is a collation of data from various systems including the corporate asset management database, transformer oil database and electrical test reports (forms), as well as information from Regional staff and ad-hoc inspections. A summary of the inputs and process described is shown below.

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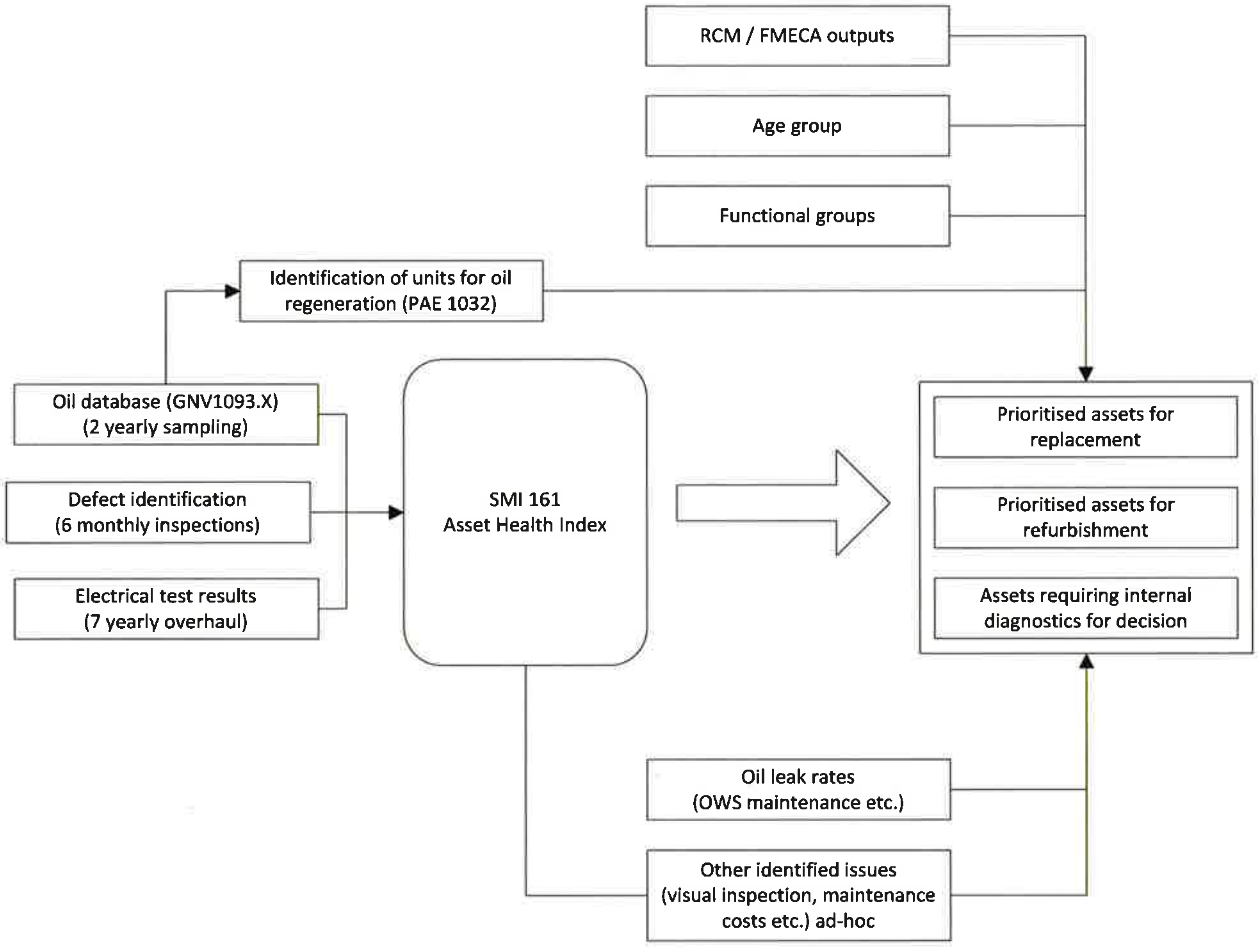

Figure 1 – Summary of the power transformer condition assessment process

2.3.1 Health index

There are 16 factors from various data sources that feed the health index for the power transformer asset class weighted by significance. The inputs are provided in the table below. While the overall health index provides a benchmark for asset replacement decisions, a number of key factors within the health index in isolation are considered, such as paper age, dissolved gas analysis and oil quality that warrant individual decisions to manage the long-term age of the assets. These are described in more detail below.

Table 5: Health index formulation

#	Condition Criteria	Weight (W_i)	Condition Rating	Factors (S_i)	Maximum Score (T_i)
1	Bushing external condition	1	A, B, C, D, E	4, 3, 2, 1, 0	4
2	Main tank and control cubicle	1	A, B, C, D, E	4, 3, 2, 1, 0	4
3	Conservator, Radiators and cooling system	1	A, B, C, D, E	4, 3, 2, 1, 0	4
4	Overall transformer condition	1	A, B, C, D, E	4, 3, 2, 1, 0	4

#	Condition Criteria	Weight (W_i)	Condition Rating	Factors (S_i)	Maximum Score (T_i)
5	Maintenance history	1	A, B, C, D, E	4, 3, 2, 1, 0	4
6	DGA oil analysis	11	A, B, C, D, E	4, 3, 2, 1, 0	44
7	Furan oil analysis	58	A, B, C, D, E	4, 3, 2, 1, 0	232
8	Transformer winding resistance	2	A, B, C, D, E	4, 3, 2, 1, 0	8
9	Transformer ratio test	1	A, B, C, D, E	4, 3, 2, 1, 0	4
10	Transformer DDF test	2	A, B, C, D, E	4, 3, 2, 1, 0	8
11	HV Bushing DDF test	5	A, B, C, D, E	4, 3, 2, 1, 0	20
12	LV Bushing DDF test	2	A, B, C, D, E	4, 3, 2, 1, 0	8
13	Insulation resistance	1	A, B, C, D, E	4, 3, 2, 1, 0	4
14	Oil quality test	3	A, B, C, D, E	4, 3, 2, 1, 0	12
15	OLTC control cubicle and mechanism components	6	A, B, C, D, E	4, 3, 2, 1, 0	24
16	Overall OLTC condition	4	A, B, C, D, E	4, 3, 2, 1, 0	16
		100			**400**

2.3.2 Paper strength (age)

The paper strength of the solid insulation provides a true indicator to the thermal age and therefore future risk of a power transformer asset to continue to sustain load and through fault currents toward end-of-life. Paper strength is measured through the chemical analysis of the polymerisation (DP) which is an integer indicating the average length of the cellulose molecule as a proportion of the shortest cellulose component within that chain. Alternatively as the paper decomposes within the power transformer due primarily to temperature and moisture condition, decomposition products are developed which include furanic compounds (2-furfuraldehyde, furfuryl alcohol, etc.), as well as gasses CO, CO_2 and liquid H_2O. These conditions are monitored at minimal cost on a 2-yearly basis for all power transformers in Endeavour Energy's network based on GNV 1093.2. Equations are used to correlate the above decomposition products to the paper strength.

There is a direct relationship between the DP and the mechanical strength of the paper. A low DP value indicates paper that is brittle and will break under mechanical load (due to sudden changes in electrical load either through network change-over or ongoing through fault operation). The end-of-life is typically considered when the DP is in the order of 150-200 whereas some experts consider paper strength in the order of 450 warrants changes to operating conditions due to the limited short circuit strength of a transformer thereafter.

There are some units in the network that show relatively low DP which does not correlate with the known loading history and age of the unit. Conversely, there are units that are relatively young in age and although loaded above average show a furan development rate which is indicative of a unit that is nearing end of life prior to expectation. Such units are identified for direct DP sampling or other diagnostic means to make future asset management decisions. These units are recommended in the conclusion of this report.

2.3.3 Dissolved gas analysis and oil quality measures

Oil testing results, which are used to score criteria such as oil quality and dissolved gas analysis (DGA), are entered into an oil database by laboratory staff in accordance with GNV1093.1. DGA provides a method based on combustible gas development of the liquid insulation under localised or distributed higher operating temperatures, and based upon a number of ratios and magnitudes of the given gasses this can be related to the type of electrical fault, and the rate of gas generation can indicate the severity of the fault. Such information can identify units for preventative maintenance or conditions that warrant replacement of the units based on an assessment of costs.

While the overall health index will drive key replacement decisions, a number of other units are identified as detailed further in Section 4 of this report based on key risk factors:

1. Units that show the high potential and severity of electrical faults by DGA are identified for further diagnostic testing. These may indicate an asset that requires more immediate non-routine preventative maintenance or further expert advice.
2. Additionally based of oil acidity and conductivity which can cause ongoing degradation of the transformer and reduced thermal capability, and where economical to do so, units may be identified for oil regeneration for the extension of life of the asset. This is detailed in PAE 1032 – identification of transformers for oil regeneration.
3. Units identified that contain high moisture content in the oil identified through oil sampling are assessed utilising polarisation depolarisation current / frequency domain spectrometry analysis to verify moisture content. This may result in a program of on-site oil drying through local heat application, oil-regeneration under heat condition or in some circumstances vacuum drying.

2.3.4 Maintenance history and increasing maintenance costs

Defect work orders are analysed for each unit and maintenance costs monitored to asses growing financial and asset risks associated with power transformer assets. Units that require significant non-routine maintenance are assessed on economic value on a case-by-case basis to determine whether the non-routine maintenance activity is justified. Section 4 of this report details one particular unit that requires significant cost to return to suitable service and is recommended the assets removal in this regard based on an assessment of site management and capacity analysis.

2.3.5 Environmental incidents and oil leaks

Power transformers contain mineral oil, which forms part of the electrical and thermal insulation systems; larger units can contain volumes of mineral oil in excess of 20,000L. Over time, the gaskets and seals on transformer pipes, valves and joints will deteriorate and there is a potential for oil leaks to develop. Another avenue for oil leaks to occur is through corrosion of metal surfaces such as the radiator fins, allowing oil to escape from rust holes.

When a transformer is leaking oil to the outside, it is also allowing moisture to transfer to the inside. This is particularly evident in rain and storm events where the transformer will cool down quickly and the pressure inside the tank drops, sucking in the moisture from the outside of the transformer.

Moisture is one of the major contributors to the ageing and degradation of the power transformer insulation system, degrading both the solid paper insulation and mineral oil. Moisture content in mineral oil accelerates the oxidation of the oil which results in acidic compounds that absorb into the solid paper insulation and further accelerate the ageing process. The breakdown of the oil also creates sludge, which sticks to and coats the metallic surfaces and solid paper insulation. This sludge affects the heat transfer from the winding to the oil, increasing the temperature of the winding.

The acidic compounds further accelerate the chemical decomposition of the paper as well. Increased moisture content in the paper insulation drastically reduces the dielectric breakdown strength, creating the potential for a flashover inside the tank. The degree of polymerisation of paper is a primary indicator of the health of a transformer and once the paper insulation degrades, it cannot be rehabilitated.

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Transformers are housed in bunds, which help contain oil leaks. Oil water separators allow storm water that accumulates in the bund to be released, while still retaining any leaked oil from the transformer bund. However, they can only hold roughly 100L of oil before they need to be emptied; otherwise the excess oil may overflow through the stormwater drainage system. With large leak rates of oil the oil water separator becomes less effective at filtering out the mineral oil and will output some mineral oil through the water drain valve. Any unplanned leak, spill or release of oil into the air, water or land from an Endeavour Energy premise, asset or worksite is reported as an environmental incident.

In September 2015 an investigation into leaking power transformers in Northern Region was undertaken following a number of environmental incidents. The environmental incidents include oil leaks outside of the bunded areas, into basements and in some cases leaving oil sheens on stormwater outlets.

The environmental incidents that prompted the investigation are listed in the following table for the period August 2014 to August 2015:

Table 6 - Previous environmental incidents due to oil leaks

Site	Incident
Baulkham Hills TS	In August 2015 following a significant rainfall event, oil sheen was detected in the stormwater outlet adjacent to the substation
Parramatta ZS	On the 5th of August 2014 oil was observed leaking from the transformer bund. The spill response contractor was engaged to periodically clean the leaking bund. The transformers from Parramatta ZS have now been disposed
Hawkesbury TS	On the 24th of February 2015 an employee visiting the TS identified unsealed control cable from transformer (TX1) bund had entered stormwater drains outside of the bund. All stormwater drains leading offsite were inspected and no oil had escaped from the site
Camellia TS	On the 18th of March 2015 an oil water separator service technician identified a minor leak from TX 2 bund onto adjacent driveway
Kingswood ZS	On the 13th of April 2015 Core IS were completing oil water separator maintenance at Kingswood ZS. They have reported oil staining on the outside of the bund indicating that the bund is leaking.
Cranebrook ZS	On the 23rd of April 2015 Oil/water separator service technician identified a minor leak from the transformer bund and staining was visible outside of the bund

In addition to the environmental incidents, a list of high leak rate transformers were identified which required excessive oil water separator servicing. This list is attached in Appendix E. These transformers are all located in the Northern Region; there were no transformers in the Central or Southern Regions with the same levels of oil leakage. This is due to a legacy of reactive maintenance on Northern region power transformers and the focus has now shifted to condition based asset management.

Where there is no alternative future strategy for replacement or significant refurbishment activity, transformers identified with excessive oil leaks will be scheduled for repairs to continue to contain effective service.

2.3.6 DBDS – dibenzyl disulphide risk

Corrosive sulphur has been identified as a serious problem in the electrical industry since 2000. It has been established that transformer oils contain reactive sulphur compounds such as dibenzyl disulphide (DBDS), which react with copper to form copper sulphide on the surface of the conductors and more significantly on the paper insulation. DBDS is classified as the key corrosive sulphur compound as it is present in the highest percentage of corrosive transformer oils, which degrades the insulation and can lead to premature failure of transformers. DBDS was commonly used as an oil inhibitor in the 1990's until the effects were later understood.

In order to mitigate the risk of copper sulphide deposition on paper insulation, there is a need to add a metal passivator the transformer oils contaminated with DBDS. Such processes have been applied on a number of units in the network already over the past couple years.

Current industrial practice and mitigation techniques are either directed at transformer winding or transformer oil in the following manner:

- Techniques that relate to transformer windings include load reduction, improved cooling and addition of metal passivators. These techniques only suppress the reaction that forms copper sulphide and do not permanently solve the issue of corrosive sulphur and therefore need to be continually monitored and controlled.

- Techniques directly associated with the transformer oil itself include oil change and oil treatment. These can help to eradicate corrosive sulphur permanently from oil given that copper sulphide is not already deposited in the active part of the transformer as then elimination of corrosive sulphur from transformer oil does not eliminate the risk of failures due to copper sulphide formation on the paper. Eradication of corrosive sulphur from transformer oil here means that its concentration is found to be < 5 ppm, in which case the oil is declared non-corrosive.

Metal passivators that are commonly used in the industry include Irgamet 39 and Nypass. The recommended concentration of passivators in transformer oil is 100 ppm. In order to gain maximum efficiency from metal passivator, it should be added to units filled with new and highly refined oil. Significant levels of passivator gets absorbed into the paper insulation and other cellulose materials, which is one factor in its depletion from oil. As suggested in various technical papers, the passivator loses its efficiency and depletes at fast rates from old and ageing oils due to the presence of hydro-peroxides, acids and high temperatures.

Absorption of metal passivator in the paper seems to provide some protection against copper sulphide deposition and by acting as a reservoir for copper conductors; however this protection is short-lived in old and ageing oils that contain oxygen and oil ageing products. Further, the addition of metal passivators is correlated with an initial increase of hydrogen gas formation but it is expected to diminish after a certain period. Thus, elevated levels of hydrogen in a DGA after passivation may lead to inaccurate conclusions and will be monitored accordingly.

2.3.7 Oxidation inhibitors

The ability of mineral electrical insulating oil to withstand oxidation under thermal stress and in the presence of oxygen and a copper catalyst is called oxidation stability. Oil oxidation leads to the breakdown of the mineral oil and these acidic by-products accelerate the ageing of the mineral oil and paper insulation of the power transformer. Refined mineral oils contain, to a varying degree, natural compounds acting as oxidation inhibitors. These are known as natural inhibitors. Oils containing only natural inhibitors are designated as uninhibited oils.

Synthetic oxidation inhibitors can be added to enhance the oxidation stability. In transformer oils, mainly the phenolic type is used and the common and generally accepted compounds are DBPC and DBP. All new Endeavour Energy transformers and selected transformers prior to 2014 have inhibitors added to their oil.

The efficacy of added inhibitors will vary with the chemical composition of the base oil. Inhibited oils have a different oxidation pattern compared to uninhibited oils. At the beginning of service life, the synthetic inhibitor is consumed with little formation of oxidation products. After the inhibitor is consumed, the oxidation rate is determined mainly by the base oil oxidation stability. When the concentration of inhibitor is reduced, there are three options, namely:

a) re-inhibition of the oil to the original value of inhibitor concentration, if other parameters show a low degree of ageing;
b) if the oil is in poorer condition, reclaim and inhibit to original concentration;
c) continue to use the oil but at low inhibitor concentrations, typically 0.05 %, increase the frequency of sampling.

The limits for inhibitor testing are stated in SMI 103 and conform to IEC 60666. The inhibitor content should be monitored at regular intervals, however it has been identified that inhibitor testing is implemented sporadically at Endeavour Energy and it is complicated by the fact that an external contractor tests for the inhibitor content. Furthermore, the Ellipse nameplate information does not accurately reflect whether a power transformer did or did not have inhibited oil when commissioned. This has led to an identified gap in inhibitor testing and the risk is that some transformers with inhibited oil are not being tested for inhibitor level.

3.0 Asset class risk and maintenance

3.1 Introduction

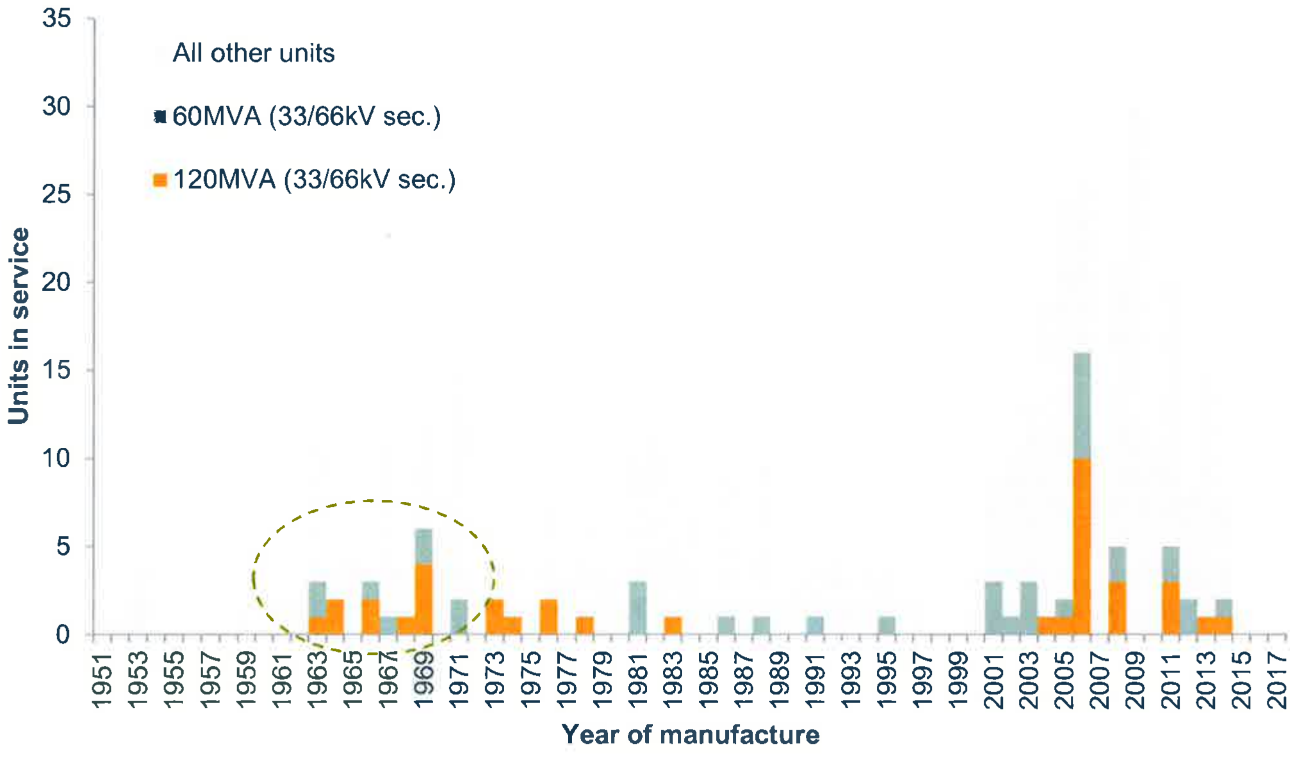
Power transformers form the backbone of the electricity distribution network, taking power from BSPs and transferring the power through transmission and zone substations to local feeders. As such, they are the primary focus of infrastructure spending for transmission and zone substations, due to their cost and extensive associated infrastructure (bunds, blast walls, cabling, busbars etc.).

The main risk to power transformers is the degradation of the insulating mediums within the transformer, which can caused electrical fault damage to internal components; or mechanical damage from the physical movement that result from an electrical fault. The two types of insulation in transformers are paper insulation of the windings and mineral oil in the main tank. Mineral oil deteriorates from exposure to heat, moisture and air. Similarly, paper insulation also degrades due to exposure to heat and moisture. Therefore, the risk of oil leaks, moisture ingress and overheating of the transformer are considered major risks to the asset health.

If a power transformer was to fail, there are several key consequences that make this a heightened risk scenario. Firstly, as it is one of the higher upstream components of the electrical distribution network, there is a large magnitude of electrical energy that is released during a fault. This manifests as arcing damage or flashovers to grounded systems as well as mechanical damage through mechanical torsion and explosive pressure release from expanding mineral oil. Furthermore, the mineral oil can ignite, which would cause a serious fire that significantly affects other substation equipment such as circuit breakers, instrument transformers and other transformers.

Apart from the safety risk to staff and members of the public in close proximity to the substation and equipment loss, the loss of a power transformer reduces the reliability of a substation, especially if another power transformer onsite is undergoing maintenance. This could also impact supply to downstream substations and distribution feeders, as operators are unable to switch around loads fed from the failed equipment.

Table 7 - Power transformer age profile by age and size



It has also been identified that there are a group of 10 120MVA transformers approaching the end of planned asset lifetime and due to their size, will require extensive investment and logistics management to replace. However, by monitoring and managing the assets' conditions, replacement programs can be staggered over successive financial years to reduce the risk of unplanned in-service failure and impact to network reliability.

3.2 History

3.2.1 Failures

In the last 10 years, the following power transformers have failed in service, or suffered faults in service and were later withdrawn:

Table 8 - Recent power transformer in-service failures (last 10 years)

Transformer	Age	Failure mode	Failure year	Cause
Kemps Creek TX 1, 33kV	46	Winding failure	2007	Age degradation
South Nowra TX 1, 33kV	?	Winding failure	2007	Internal fault
Warragamba TX 2, 33kV	46	Failed	2007	N/A (no post-fault analysis conducted)
Appin TX 1, 66kV	24	Failed	2008	Partial discharge
Guildford TS TX 3, 132kV	52	Internal fault	2009	Age degradation
Inner Harbour TX 3, 33kV	47	Winding failure	2010	Age degradation
Baulkham Hills TX 2, 132kV	46	High post-fault DGA	2012	OLTC high resistance on B-phase
South Granville TX 2, 33kV	44	Tapchanger failed	2012	Failure of OLTC insulation
Lithgow TX 2, 66kV	31	High DGA and failed PD test	2013	Partial discharge
Bow Bowing TX 3, 66kV	35	Internal fault	2014	Potential manufacturing defect in HV winding entry
West Wollongong TX 3, 33kV	12	Internal failure	2014	Potentially insufficient fault withstand capability
Luddenham TX 2, 33kV	12	LV winding failure	2017	Under investigation

The main failure type for in-service power transformers is winding failure, through degradation of the winding insulation. They fail due to the electrical stress of an external fault, or from deterioration of the paper insulation due to moisture content in oil, elevated operating temperatures / high loading and manufacturing imperfections.

Of the failures, two power transformers failed less than half way into their planned asset lifetime. The first, Appin TX 1, was withdrawn from service due to high hydrogen levels after a Buchholz trip. This was caused by partial discharge. There is another sister unit in service, Wentworth Falls TX 1, however this unit does not have the same issues as Appin TX 1.

The more recent failure, Luddenham TX 2, is yet to be examined in depth however it has an uncommon aluminium foil winding construction for the LV windings. There are only two more units of the same construction in service, which are also sister units, Luddenham TX 1 and Cattai TX1 and they do not have any issues thus far.

3.2.2 Past investment approach

A number of programs and initiatives to manage the asset failure risk for power transformers were carried out in the past. Namely:

- TS001 / TS600 – power transformer replacement
- TS017 – power transformer refurbishment
- TS018 – transformer oil replacement

These programs were proposed and managed through the SARP in previous years, to address the condition degradation of power transformers and associated assets to reduce the risk of unplanned failure, increase network reliability.

The power transformer replacement program, TS001/TS600 focussed on replacing end-of-life transformers, either due to age or conditional degradation. Previously, this was based on the condition of the paper insulation (using DP samples) or analysis of furan levels. Moving forward, the assessment criteria for the replacement of power transformers will include all the factors detailed in SMI 161 Section 3, to incorporate as many facets of the transformer's asset health and operational history as possible.

TS017 – power transformer refurbishment was a program that provided mid-life refurbishment of power transformers, so that it would achieve its full life expectancy. Selection of transformers for refurbishment was influenced by the age, condition and maintenance history of the transformers.

Asset class condition assessment will continue to identify transformers to be refurbished, based on cost-benefit analysis of keeping the unit in service versus the remaining depreciated life of the asset.

The scope of the power transformer oil replacement program, TS018, was to replace or regenerate poor quality oil in power transformers identified through routine oil testing. Oil is subjected to heat, moisture, air, electrical stress and a host of other factors and the quality of the oil is an indicator of the overall health of the transformer. In the future, power transformers will be identified for oil regeneration and replacement, based on the oil quality and DGA results.

The program for noise attenuation in ZS and TS, TS026, was initiated to address issues relating to noisy transformers and their compliance with environmental noise regulations. Some substations are sited within residential areas and residential development has occurred around older substations and with that, there is a possibility that nearby residents will complain about substation noise. While this issue relates to power transformers, it was driven by environmental compliance rather than asset condition and will be managed in the future through specific programs as required.

3.3 Key maintenance tasks for the asset class

The standard governing the maintenance of power transformers is SMI155 and the intervals are contained in SMI100. There are three types of routine maintenance carried out on power transformers, which are:
- 6 monthly inspections
- 2 yearly oil tests
- 7 yearly major overhauls

The 6 monthly inspections comprise of visual inspections tasks and operational checks, which are carried out as part of the 6 monthly substation inspections or before commencing a major overhaul. The tasks undertaken during the 6 monthly inspections are:
- Visual inspection of external condition of power transformer components, to note any damage or deterioration to transformer components.
- Operational checks of the cooling pumps and fans

Oil testing frequency is specified in SMI 100. In the case of new power transformers, an oil test is conducted every 4 months for the first year, then 12 monthly until the end of the warranty period. After the warranty period, all power transformers are tested at 2 yearly intervals. The following oil tests are carried out:
- Furan analysis
- Oil quality
- DGA

Major overhauls of power transformers are carried out every 7 years, along with the major overhaul of tap changers. The major overhaul tasks are:

- Visual inspection tasks as per 6 monthly inspection
- Transformer signature tests:
    - IR and PI
    - Winding DDF and bushing DDF
- Cleaning of bushings and insulators
- Operational checks of heaters and cooling system
- Inspection of control wiring and terminations

Additionally, the tapchanger overhaul is conducted concurrently with the power transformer major overhaul or on number of operations in accordance with SMI151 and DC winding resistance test carried out.

The annual per-unit and total costs for maintaining power transformers is listed in the following table. Noting this does not include the 6-monthly substation inspection task:

Table 9 - Summary of maintenance task costing

Maintenance Task	Annual cost (per unit)	Total annual cost
2 yearly oil test	$100*	$45,400*
7 yearly power transformer major overhaul	$544	$247,106
1 yearly tap changer carbon drain	$3,010	$162,540
7 yearly tap changer major overhaul	$509	$168,526
7 yearly tap changer major overhaul (Reinhausen - internal)	$624	$39,963
7 yearly tap changer major overhaul (Reinhausen - external)	$2,340	$138,043

** The oil test cost does not include the cost of managing and maintaining an oil laboratory at Springhill which primarily tests oil for power transformers.*

Spares are managed through an essential spares process detailed in GAM 1096. This includes spare power transformers of various sizes and voltages at key depots such as Mt Druitt TS and Springhill TS. Also, essential spares such as high voltage bushings are stored at FSCs and the Glendenning CLF.

For oil leaks, the calculated costs for topping up lost oil and maintaining the oil-water separators are estimated below:

Table 10 - Summary of oil leak maintenance costing (per unit, per annum)

Maintenance Task	Task cost (per unit, per annum)
Oil-water separator maintenance (6 monthly)	$2,500
Topping up oil (labour)	$300
Oil cost (100L)	$350

For a unit such as Hawkesbury TX 1, which was leaking 1100L of oil per year in 2015, this approximates to an additional $10,000 per year in additional maintenance costs. Units with heavy oil leaks, including this example are identified in Section 4.2.2 for refurbishment programs to repair the oil leaks.

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3.4 RCM and FMECA

Endeavour Energy has adopted the RCM (reliability centred maintenance) process to review the maintenance requirements for its assets. The process provides transparent and auditable traceability between the maintenance tasks undertaken on an asset, the functions the asset delivers for the network, and the related inherent failure modes.

The analysis process utilises a quantified failure mode effects and criticality analysis (FMECA) combined with reliability centred maintenance (RCM) approach. The underlying algorithms for determining optimum task periods for 'on condition' and 'failure finding' tasks are embodied within a RCM program called MIMIR. This ensures that only tasks which are both applicable to the failure root cause and effective in managing the potential consequences of the failure form tasks in the maintenance schedules/standards developed by the process. The process above is in alignment with Company Policy (Network) 9.9.1 – Network Asset Maintenance and methodology prescribed in PAE 1054 – Reliability centred maintenance.

From the RCM analysis, the failure modes that drive the 7 yearly major overhauls are:

- Bushing failure due to insulation degradation
- Winding insulation failure due to insulation degradation
- Cooling fan failures due to internal faults

On-load tap changer (OLTC) are another risk and there have been in-service failures of power transformers due to the OLTC failing. While maintenance of the OLTC is carried out simultaneously with the power transformer major overhaul every 7 years, it was analysed as a separate asset class and will be examined in a separate asset condition class report.

FMECA concluded that not all failures can be detected early using condition monitoring. For example, the condition of the Buchholz relay cannot be assessed via the oil and electrical testing and therefore, as a minimum, requires routine checks to ensure that it is operating correctly. Periodic testing and maintenance tasks are still required and are carried out during the scheduled maintenance tasks.

3.4.1 Site criticality

Site criticality is a factor in determining the priority of transformer replacement. While a particular asset may be in poor condition, the location of the substation, operational profile and the condition of the site's other transformers are also weighted to produce a site criticality score. A list of these factors is:

- Proximity to nearby structures (safety) – proximity to residential or commercial infrastructure
- Types of load (reputation) – Number of life support customers, HV customers and total load loss
- Potential reliability impact (reliability) – Number of potential customers lost and loss of operational capability to feed downstream sites.
- Proximity to sensitive environments (environment) – proximity to national parks, wetlands and other environmentally sensitive areas.
- Asset value (financial) – Cost to repair/replace asset, including installation costs

3.4.2 Failure rates and defects

The failure rates for power transformers are contained in Appendix F. There is no abnormal failure rates observed compared to industry.

3.5 Data and system compliance gaps

3.5.1 Equipment compliance

The current equipment information shortfall for power transformers is the lack of online condition monitoring equipment. The most frequent maintenance tasks are the 6 monthly inspections and 2 yearly oil tests, which do not provide real-time assessments of the transformer's condition. While DGA is capable of detecting some internal failure modes pre-emptively, these tasks are generally reactive and provide conditional assessment only after a power transformer suffers damage.

This was a finding from the FMECA, however due to the size of the power transformer fleet and cost of online monitoring equipment, it is not cost-effective to install on all power transformers. It is proposed that existing data sources, such as equipment loading information and oil temperature be investigated to see if they can be leveraged to provide more currency on condition assessment of power transformer health and whether that can augment the monitoring of poor health transformers. This is useful especially for units in the Monitor & Assess (M&A) range, where extended periods of overheating or overloading could further deteriorate the condition of power transformer. This will enable the Substation Assets group to proactively re-prioritise power transformers to either replace or repair units that have deteriorated, or to delay refurbishment activity on monitored transformers if their health is stable.

Another benefit of online condition monitoring is that, if pre-emptive signs of failure are detected, an unplanned outage can be avoided or minimised. Even a short unplanned outage on a Transmission Substations power transformer can cause millions of dollars in STPIS penalties and for a comparatively small investment in research and development to improve existing data systems, online condition monitoring is a cost effective solution.

3.5.2 Data compliance

Currently, the main issue with compiling data for the asset health condition of power transformers is that streams of data are deposited into separate databases, with no native connectivity between these sources. The following table shows the data stream and database of the sourced information:

Table 11 - Sources of data input for asset condition assessment

Data source	Database
Transformer nameplate data	Ellipse
Work order history	Ellipse
Oil test results	Access database
Electrical test results	G:\EE Maintenance

This presented issues when compiling the data for the health assessment, as all the different data sources had to be exported to a common format (Excel), matched by equipment number and then ranked and processed. Multiple sort and move operations increase the likelihood of mistakes being made when analysing the data. Additionally, there are some minor discrepancies between the Ellipse asset management database and other data sources, due to operator error when entering nameplate details. In this instance, the Ellipse database information was preferred and in some instances, the actual transformer nameplate was sourced to correctly ascertain this information.

Another issue was the currency of status for transformer nameplate data. As the asset management database is not linked at all with the oil test database, tracking of spare or replacement transformers is not consistent. Due credit is given to the regional field and oil testing staff, who do correctly assign test results to the transformer serial number, which is traceable even if a spare transformer is placed in service. Moving forward, the regional staff collecting the oil must notify the Substation Asset group if a spare unit is put into service and disclose the nameplate details of the spare transformer. They will also update both Ellipse and the oil database to reflect the change in transformer status. In turn, the Substation Assets group will regularly audit the oil database and ensure that the information is consistent with the Ellipse database.

There is an information gap identified for certain sections of the electrical test history for power transformers. As seen in the table below, some electrical test results are not accessible due to either corruption of files or being stored in the incorrect format (e.g. as pdfs, docx, tif).

Table 12 - Summary of data validation for electrical test records

Region	Readable	Matches Ellipse WOs
Northern	92%	72%
Central	87%	57%
Southern	86%	42%

Additionally, when compared against Ellipse work orders, it was found that there was a discrepancy between the two. This indicates that either the related work orders in Ellipse are not being raised correctly to the power transformer asset or standard job, or that signature tests are carried out without an accompanying work order. It is proposed that further dialogue be conducted with regional staff to highlight the importance of data collection and storage, as well as to come up with a bipartisan solution to improve the quality of data collection.

To address the overall data sourcing issue, it is proposed that a centralised data resource be compiled, which periodically updates from the each of the identified data sources above.

4.0 Asset condition assessment

4.1 Introduction

As outlined in Section 2.3, the condition assessment for power transformers was comprised of the following data sources:

- Transformer oil quality and DGA test reports
- Maintenance electrical test reports
- Ellipse defect work orders
- Input from regional staff
- Substation Asset group investigations for oil leakage and corrosive sulphur

4.2 Condition summary

Using health index scoring based on SMI161 Section 3, the fleet of power transformers have been categorised into 4 groups:

1. End-of-life (EOL1) – Health index score <70
2. Nearing end of effective life (EOL2) – Health index score 70 – 220, or operational age >50 years
3. Monitor and assess (M&A) – Operational age > 50, or conditional issue identified
4. Conditional maintenance (CM) – Health index score >230 and operational age < 50 years

The one transformer in EOL1 is Nepean TX 3 and it has been prioritised for replacement in 2017/18. There are a further 33 transformers in the EOL2 group, of which 17 will be considered for replacement in the next SARP for upcoming financial years by the Asset Standards & Design and Asset Strategy & Planning groups. A further 7 units were identified to have DP tests carried out in FY 2017/18. While the conditional score for Minto TX 1 was not as low as the other in this group, it was identified as an outlier as its conditional score was significantly lower for its age group and a DP test will be undertaken to ascertain its paper insulation condition. The remaining 9 units in EOL2 will be monitored for any further deterioration and be re-assessed for remedial works in subsequent financial years.

The third group, M&A, contains 3 transformers that are scheduled for DP testing in 2017/18. This is due to the fact that they have extensive oil leaks. This means that the oil results for these particular transformers may not be indicative of their conditional health and a direct DP measurement is required. Although Camellia TX2 is not part of this group, all Camellia TS units have been assessed for site renewal, as detailed in Appendix A. The remaining transformers in this are to be monitored primarily due to their operational age and will be re-assessed in future conditional analyses.

Apart from the 4 conditional classes, there were a further 3 groups identified for remediation due to oil quality issues:

1. Oil leaks and refurbishment
2. Oil regeneration and replacement
3. Oil passivation

The list of power transformers requiring oil leak remediation and refurbishment is contained in Appendix E and those that didn't fit into EOL1 and EOL2 were listed in Section 4.2.2. This includes Camellia TX2, which is assessed as part of Statement of Needs for Camellia TS as whole in Appendix A. The other transformers in this list have satisfactory health index scores and are scheduled for refurbishment to remedy the oil leaks.

Units identified for oil regeneration or replacement, were identified by their poor oil quality, but acceptable health index scores and asset age. There are a total of 6 units identified and upon further assessment, they will undergo either regeneration of their oil using online filtration or complete replacement of their oil. Age indicators, such as furan analysis, will be recorded prior to oil replacement.

Finally, a group of transformers were tested for DSBS and they are listed in Section 4.2.4. These units will be dosed with oil passivators to counteract the corrosive sulphur content present in the oil. Further units may be added to this list if they are found to contain DSBS compounds.

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4.2.1 Health index identified units

The health index for the power transformer fleet by age and size (bubble size reflects units MVA rating) is shown below, along with the various assessment categories:

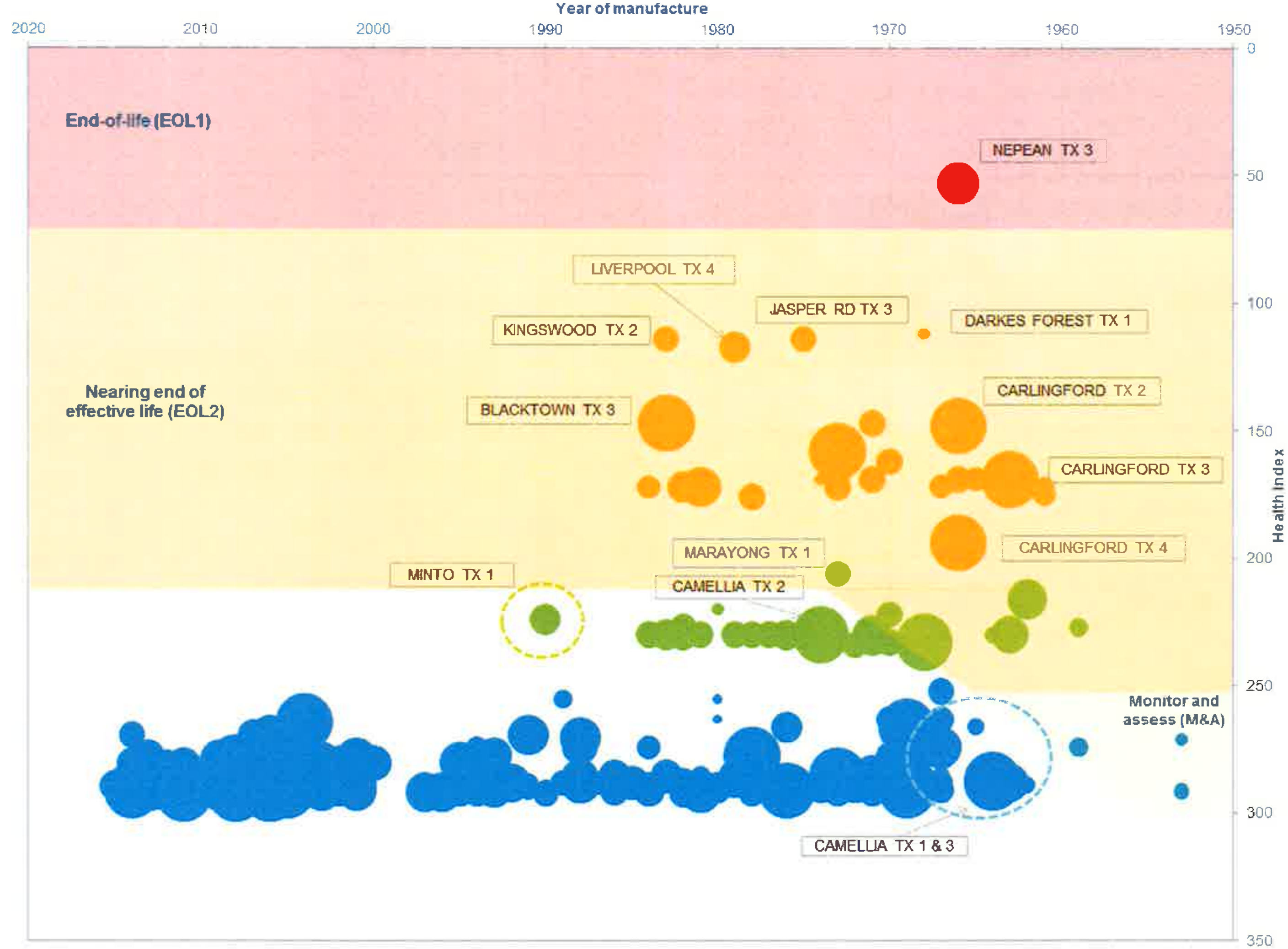


Figure 2 - Visualisation of power transformer condition assessment

As a table, the units shown in the plot above are detailed further below with the proposed strategy for the unit and a number of the key factors driving the decision.

Table 13 - Power transformer asset condition assessment (prioritised units)

Rank	Name	EID	Year	Size MVA	Score	2FAL	Date	DP	Date	Strategy	Site risk criticality
1	NEPEAN TS, 132kV, No 3 Transformer	188265	1966	60	53	0.66	2015	129	2010	Planned for disposal 17/18 (unit is surplus of needs)	3.0
2	DARKES FOREST ex BERRY ZS, 33kV, No 3 Transformer	175139	1968	5	112	0.11	2016	255	2008	Plan replacement	1.6
3	JASPER ROAD ZS, 33kV, No 3 Transformer	184792	1975	25	114	1.76	2017	250	2013	Plan replacement	2.4
4	KINGSWOOD ZS, 33kV, No 1 Transformer	184306	1983	25	114	4.65	2015	394	2005	Plan replacement	2.4
5	KINGSWOOD ZS, 33kV, No 2 Transformer	184285	1971	25	169	2.5556	2015	302	2011	Plan replacement	2.4
6	LIVERPOOL ZS, 33kV, No 4 Transformer	183352	1979	35	117	0.3016	2017	201	2013	**DP result suspect - retest**	2.8
7	SOUTH NOWRA , 33kV, No 1 Transformer	184545	1971	25	147	1.1458	2016	275	2007	Plan replacement	2.4
8	BLACKTOWN TS, 132kV, No 3 Transformer	186716	1983	120	147	3.5	2015	443	2006	Re-evaluate unit in 17/18 for decision	3.0
9	PROSPECT ZS, 33kV, No 2 Transformer	187902	1965	15	169	0.6	2015	331	2010	Plan replacement - refer Appendix B; priority determined in consultation with AS &P.	2.4
10	PROSPECT ZS, 33kV, No 1 Transformer	187915	1961	15	172	1.01	2014	275	2013		2.4
11	CARLINGFORD TS, 132kV, No 2 Transformer	186368	1966	120	148	2.0978	2016	*818*	*2012*	Need to renew 3 TX's at Carlingford TS - other site issues warrant complete renewal plan for substation. (TX2 DP result unrepresentative [from delta winding])	3.0
12	CARLINGFORD TS, 132kV, No 4 Transformer	186291	1966	120	194	1.6725	2016				3.0
13	CARLINGFORD TS, 132kV, No 3 Transformer	186325	1963	120	169	0.21	2016	321	2013		3.0
14	WEST LIVERPOOL TS, 132kV, No 2	184986	1973	120	158	1.3353	2016	311	2011	Re-evaluate unit in 17/18 for decision	3.0
15	HORSLEY PARK ZS, 33kV, No 3 Transformer	184345	1970	25	162	0.2274	2016	344	2005	*Monitor*	1.9
16	MARAYONG ZS, 33kV, No 3 Transformer	187932	1973	25	166	3.2277	2015	398	2007	Marayong site subject to planned renewal. Replace at minimum 1 transformer. Refer Appendix D.	2.1
17	MARAYONG ZS, 33kV, No 2 Transformer	187957	1973	25	172	2.19	2016	446	2007		2.1
18	MARAYONG ZS, 33kV, No 1 Transformer	187976	1973	25	206	1.84	2016	387	2007		2.1
19	ALBION PARK ZS, 33kV, No 3 Transformer	178328	1959	12.5	227	1	2015			Plan replacement - refer Appendix C; priority determined in consultation with AS &P.	1.5
20	ALBION PARK ZS, 33kV, No 2 Transformer	178327	1959	12.5	274	0.89	2015				1.5
21	BERRIMA JUNCTION ZS, 33kV Transformer No.1	187289	1965	20	169	0.09	2016	313	2007	*Monitor*	1.9
22	LEABONS LANE ZS, 33kV, No 3 Transformer	185380	1966	25	169	2.5	2016			**DP sample required**	2.4
23	GERRINGONG ZS, 33kV, No 3 Transformer	175134	1974	5	169	0.28	2015	313	2012	TX2 replaced at Gerringong under TS615 and TX3 minor refurbishment. Continue to monitor TX3 which is surplus to need.	1.5
24	HOLROYD ZS, 33KV, No 1 Transformer	182449	1964	17.25	169	0.18	2017	328	2012	Plan replacement	2.4
25	WILTON ZS 66kV No 2 Transformer	881174	1967	20	172	0.3587	2017	262	2007	Plan replacement	2.0
26	FAIRFAX LANE TS, 132kV, No 3 Transformer	175071	1981	60	172	0.46	2017	310	1999	**DP sample required**	2.6
27	ST MARYS ZS, 33kV, No 1 Transformer	185272	1984	19	172	2.3769	2015	396	2007	*Monitor*	1.9

Rank	Name	EID	Year	Size MVA	Score	2FAL	Date	DP	Date	Strategy	Site risk criticality
28	CAMPBELLTOWN ZS, 66kV, No 2 Transformer	182894	1982	35	172	2.3334	2016	466	2007	*Monitor*	2.8
29	BLACKMANS FLAT ZS, 66kV, No 1 Transformer	187849	1961	17.5	175	0.9516	2015	330	2006	*Monitor*	1.9
30	EMU PLAINS ZS, 33kV, No 3 Transformer	183481	1978	25	176	0.606	2015	341	2005	*Monitor*	1.9
31	OUTER HARBOUR TS, 132kV, No 1	177521	1962	60	216	1.9244	2015			**DP sample required**	2.6
32	MINTO ZS, 66kV, No 1 Transformer	182997	1990	35	224	1.61	2015			Poor oil indicators for age - **DP test for benchmark**	2.3
33	WEST WOLLONGONG ZS, 33kV, No 2	902788	1964	10	230	0.07	2015	427	2005	**DP sample required**	3.3
34	LAWSON TS, 132kV, No 1 Transformer (ex no. 3)	183105	1963	52	230	1.13	2016			**DP sample required**	2.5
35	LAWSON TS, 132kV, No 2 Transformer	183142	1963	52	288	0.75	2016			**DP sample required**	2.5
36	CULBURRA ZS, 33kV, No 2 Transformer	175097	1965	10	266	0.01	2016			*Monitor*	1.5
37	KANDOS ZS, 66kV, No 1 Transformer	188535	1953	5	271	0.25	2016			To be evaluated in 17/18	2.0
38	KEMBLA GRANGE ZS, 33kV, No 1 Transformer	190030	1963	10	285	0.27	2015			*Monitor*	1.3
39	KEMBLA GRANGE ZS, 33kV, No 2 Transformer	841819	1963	10	285	0.12	2015			*Monitor*	1.3
40	UNANDERRA ZS, 33kV, No 3 Transformer	175132	1963	12.5	285	0.02	2016			*Monitor*	2.0
41	UNANDERRA ZS, 33kV, No 2 Transformer	175131	1963	12.5	286	0.13	2016			*Monitor*	2.0
42	OAKDALE ZS, 33kV, No 1 Transformer	182861	1963	10	285	0.26	2015	544	2012	*Monitor*	1.8
43	OAKDALE ZS, 33kV, No 2 Transformer	182827	1963	10	291	0.18	2015			*Monitor*	1.8
44	MEADOW FLAT ZS, 66kV, No 1 Transformer	189411	1965	2.5	285	0.1128	2015			*Monitor*	1.5
45	ILFORD HALL ZS, 66kV, No 3 Transformer	189247	1965	2.5	285	0.15	2016			*Monitor*	2.6
46	CAMELLIA TS, 132kV, No 3 Transformer	185538	1964	120	287	0.63	2015			Conditional issues with unit - age indicators not considered reflective of age - refer appendix A. Site running at N-2, replace 1 unit, remove 2.	3.5
47	CAMELLIA TS, 132kV, No 1 Transformer	185628	1964	120	288	0.12	2017				3.5
48	BOWRAL ZS, 33kV, No 2 Transformer	885771	1965	10	287	0.28	2017			*Monitor*	2.3
49	BOWRAL Z/S, 33kV, No 1 Transformer	175116	1965	10	288	0.27	2017			*Monitor*	2.3
50	WOMBARRA ZS, 33kV, No 2 Transformer	175075	1962	5	288	0.02	2016	450	1999	**DP sample required**	2.4
51	WOMBARRA ZS, 33kV, No 1 Transformer	175074	1962	5	288	0.05	2016	521	1999	*Monitor*	2.4
52	WARILLA ZS, 33kV, No 3 Transformer	175138	1963	10	288	0.06	2015			**DP sample required**	2.0
53	WARILLA ZS, 33kV, No 2 Transformer	902785	1962	10	289	0.01	2015			*Monitor*	2.0
54	UNANDERRA ZS, 33kV, No 1 Transformer	175130	1963	12.5	288	0.0463	2016			*Monitor*	2.0
55	BLACKHEATH ZS, 66kV, No 2 Transformer	183212	1953	7	291	0.06	2015	450	2000	To be evaluated in 17/18	2.0
56	BLACKHEATH ZS, 66kV, No 1 Transformer	183236	1953	7	292	0.27	2015	530	2007		2.0

4.2.2 Units requiring major repairs or refurbishment

Based on oil leak, general condition and after consideration for the strategies determined in 4.2.1, the following tables lists the power transformers that require refurbishment works, primarily to address concerns associated with leaking.

Rank	Name	EID	Age	Voltage Ratio - Capacity	Oil pumped out p.a.	2FAL	Date	DP	Date	Strategy	Site risk criticality
1	CAMELLIA TS No 2 Transformer	185579	41 (1974)	132/33kV - 120MVA	710	1.45	2015	492	1997	Refurbish transformer under Camellia TX works.	3.5
2	CRANEBROOK ZS No 2 Transformer	183550	38 (1977)	33/11kV - 25MVA	70	1.1008	2015			Refurbish transformer; leaks affecting basement	1.9
3	HAWKESBURY TS No 1 Transformer	184141	42 (1973)	132/33kV - 120MVA	1100	0.39	2016			Leak repairs required; leaks affecting stormwater	3.0
4	BAULKHAM HILLS TS No 4	185775	44 (1971)	132/33kV - 60MVA	120	1.41	2015			Leak repairs required; leaks affecting stormwater	2.6
5	MT DRUITT TS No 1	502372	46 (1969)	132/33kV - 120MVA	250	0.2819	2015	513	2006	Leak repairs required	3.0
6	MT DRUITT TS No 3 Transformer	578378	47 (1968)	132/33kV - 120MVA	650	1.4092	2015			Leak repairs required	3.0
7	QUAKERS HILL ZS No 1 Transformer	183860	48 (1967)	132/33kV - 60MVA	350	0.4124	2016			Leak repairs required	2.6
8	KELLYVILLE ZS No 3 Transformer	184739	46 (1969)	33/11kV - 25MVA	210	0.35	2016			Leak repairs required	1.9
9	KELLYVILLE ZS No 2 Transformer	184753	46 (1969)	33/11kV - 25MVA	240	0.3469	2016			Leak repairs required	1.9
10	ROSEHILL ZS No 1 Transformer	187594	41 (1974)	33/11kV - 25MVA	480	0.24	2016			Leak repairs required	2.1
11	ROSEHILL ZS No 2 Transformer	187569	42 (1973)	33/11kV - 25MVA	320	0.33	2016			Leak repairs required	2.1

4.2.3 Units requiring oil regeneration or replacement

The units identified for oil regeneration or replacement, were identified by their poor oil quality based on the process determined in PAE 1050, but have acceptable health index scores. There are a total of 6 units identified and upon further assessment, they will undergo either regeneration of their oil using online filtration or complete replacement of their oil. Age indicators, such as furan analysis, will be recorded prior to oil replacement or regeneration for continued management.

Name	EID	Age	Manufacturer	Oil Vol. (L)	Oil Condition Score (3 is worst)
SOUTH WINDSOR ZS, 33kV, No 3 Transformer	183875	1990	Tyree Transformers	9729	3
BRINGELLY ZS, 33kV, No 1 Transformer	502162	1982	Tyree Transformers	9729	2

Name	EID	Age	Manufacturer	Oil Vol. (L)	Oil Condition Score (3 is worst)
WETHERILL PARK ZS, 132kV, No 1	189743	1984	Westinghouse	26000	2
PORTLAND ZS, 66kV, No 1 Transformer	189195	1988	Tyree Transformers	15209	1
BOW BOWING ZS, 66kV, No 1 Transformer	189278	1983	Acec (Charleroi / Altieris)	12995	2
KENNY STREET ZS, 33kV, No 2 Transformer	885772	1988	Tyree Transformers	N/A	3

4.2.4 Units requiring oil passivation

Units determined to dope with metal passivator based on DBDS risk are detailed in the table below:

Name	EID	Manufacturer	Oil Vol. (L)	Date Tested for DBDS	DBDS Conc. (ppm)	Date Manufactured
MINTO ZS, 66kV, No 3 Transformer	182951	GEC	17500	23/12/2011	156.76	1/01/1979
CABRAMATTA ZS, 33kV, No 2 Transformer	183942	TYREE	8305	13/03/2012	N/A	1/01/1984
PRESTONS ZS, 33kV, No 1 Transformer	944106	WILSONTR	10000	3/03/2014	180	1/01/2001
YENNORA ZS, 33kV, No 1 Transformer	999084	WILSONTR	10000	3/03/2014	185	1/01/2001
PRESTONS ZS, 33kV, No 2 Transformer	944107	WILSONTR	10000	3/03/2014	181	1/01/2001
YENNORA ZS, 33kV, No 2 Transformer	999099	WILSONTR	10000	3/03/2014	173	1/01/2002
HOLROYD ZS, 33kV, No 2 Transformer	1004132	WILSONTR	10200	21/06/2013	188	1/01/2002
WEST WOLLONGONG ZS, 33kV, No 1	1089257	WILSONTR	7435	24/01/2014	165	1/01/2002
BOLONG ZS, 33kV, No 1 Transformer	979113	WILSONTR	7435	3/03/2014	187	1/01/2002
HOLROYD ZS, 33kV, No 3 Transformer	1004168	WILSONTR	10200	21/06/2013	210	1/01/2002
ALBION PARK ZS, 33kV, No 1 Transformer	967859	WILSONTR	7435	3/03/2014	185	1/04/2002
BAULKHAM HILLS TS, 132kV, No 2 Transform	1135851	ABB	28850	18/02/2013	169	1/01/2003
HOMEPRIDE ZS, 33kV, No 1 Transformer	1081875	WILSONTR	10200	3/03/2014	214	1/12/2003
GREYSTANES ZS, 33kV, No 1 Transformer	1118132	WILSONTR	10200	3/03/2014	218	1/12/2003
NARELLAN ZS, 66kV, No 1 Transformer	1162372	WILSONTR	N/A	3/03/2014	204	7/06/2005

5.0 Recommendation

5.1 Summary

The conditional assessment of power transformers was generated in accordance with SMI161 – Asset Health Index which is a collation of data from various systems including the corporate asset management database, transformer oil database and electrical test reports (forms), as well as information from Regional staff and ad-hoc inspections.

A number of power transformers were identified as being in poor health and these transformers were classified into 3 groups – EOL1, EOL2 and M&A. A further 3 categories of transformers were also identified, which had good asset health but issues with their oil quality. These groups were the oil leak refurbishment group, oil regeneration / replacement group and the oil passivator group. A more detailed summary of these groups is listed in Section 5.2 below.

It has also been identified that there is an aging group of 120MVA transformers approaching the end of planned asset lifetime. A total of 10 120MVA transformers are aged 48 years or older and due their size, will require extensive investment to replace. However, by monitoring and managing the assets' conditions, replacement programs can be staggered over successive financial years to reduce the risk of unplanned in-service failure and impact to network reliability.

5.2 Asset prioritisation / process

A summary of the power transformer asset class condition assessment is as follows:

Criteria / Strategy	Recommendation
End of life (EOL1) (Section 4.2.1)	• 1 transformer, Nepean TX 3, prioritised for replacement in 2017/18
Nearing end of life (EOL2) (Section 4.2.1)	• 32 transformers in the EOL2 group • 17 to be considered for replacement • 7 units were identified to have DP tests carried out in FY 2017/18 • 9 units will be monitored for any further deterioration and assessed further in 17/18 FY; if deterioration occurs, the units will be programmed for replacement.
Potential risk – monitor and assess (M&A) (Section 4.2.1)	• 3 transformers that are scheduled for DP testing in 2017/18 • 18 to be monitored for change in condition and elevation to EOL2 if health score deteriorates.
Oil leaks and refurbishments (Section 4.2.2)	• 11 transformers to be refurbished to repair oil leaks and maintain transformer health
Poor oil quality – oil regeneration or replacement (Section 4.2.3)	• 6 transformers identified for oil regeneration or replacement
DBDS risk - oil passivation (Section 4.2.4)	• 15 transformers to be dosed with oil passivators to treat DBDS risk

5.3 Other recommendations

5.3.1 Oxidation inhibitors

Due to the identified gap in identifying which transformers have inhibitors added to their oil and which transformers are required for regular inhibitor testing, it is proposed that inhibitor testing be conducted as a standard test for all transformer oil testing and that the testing be conducted in-house at the Endeavour

Energy oil testing facility, as much as possible. As inhibited oil is now standard for all new transformers and the volume of inhibitor testing will increase beyond the current levels (approx. 20 per year), it is forecasted that this is the more cost-effective solution than outsourcing to a contractor as per the current practice.

5.3.2 Equipment compliance deficiencies

The current equipment deficiency for power transformers is the lack of online condition monitoring equipment. The most frequent maintenance tasks are the 6 monthly inspections and 2 yearly oil tests, which do not provide real-time assessments of the transformer's condition. It is proposed that existing data sources, such as equipment loading information and oil temperature be investigated to see if they can be leveraged to provide more currency on condition assessment of power transformer health and whether that can augment the monitoring of poor health transformers.

5.3.3 Data compliance

Currently, the main issue with compiling data for the asset health condition of power transformers is that streams of data are deposited into separate databases, with no native connectivity between these sources. Another issue was the currency of status for transformer nameplate data. As the asset management database is not linked at all with the oil test database, tracking of spare or replacement transformers is not consistent.

To address the overall data sourcing issue, it is proposed that a centralised data resource be compiled, which periodically updates from the each of the identified data sources above.

There is an information gap identified for certain sections of the electrical test history for power transformers. It is proposed that further dialogue be conducted with regional staff to highlight the importance of data collection and storage, as well as to come up with a bipartisan solution to improve the quality of data collection.

Appendix A Camellia TX1 and TX3 statement of need

Appendix B Prospect condition assessment

Appendix C Albion Park condition assessment

Appendix D Marayong condition assessment

Appendix E Major oil leak transformers

EID	Power Transformer	Serial No.	Manufacturer	Age	Voltage Ratio -Capacity	Oil pumped out 14/15 (L)	Leakage and condition description/evaluation	Extent of leak	Number of locations/ Area of leak	Leak Score /10
185775	BAULKHAM HILLS TS No 4	A31B2534/2	ENGLISHE	44 (1971)	132/33kV - 60MVA	120	Top lid gasket worn out	Major	4	7
							132kV Bushing (A and B-phase) turret gasket worn out	Major	2	
							33kv Bushing (A and B-phases)turret gasket worn out	Major	2	
185628	CAMELLIA TS No 1 Transformer	284654	CANADAGE	51 (1964)	132/33kV - 120MVA	520	Top lid gasket worn out	Major	3	6
							Top radiator connection gasket worn out	Major	All	
185579	CAMELLIA TS No 2 Transformer	*8035/2	ENGLISHE	41 (1974)	132/33kV - 120MVA	710	Top lid gasket worn out	Major	4	9
							33kv Bushing turret gasket worn out	Major	1	
							Bottom radiator connection gasket worn out	Major	All	
185538	CAMELLIA TS No 3 Transformer	284653	CANADAGE	51 (1964)	132/33 - 120MVA	20	Rust - Cable box TX interface	Major	All across	6
							Top radiator connection gasket worn out	Major	All	
881225	CARLINGFORD TS No 1 Transformer	70839	TYREE	37 (1978)	132/66kV - 120MVA	570	132kV Bushing (B-phase) turret gasket worn out	Major	2	9
							Bottom radiator connection gasket worn out	Major	All	
							66kV Bushing (B-phase) turret gasket worn out	Major	1	
186368	CARLINGFORD TS No 2 Transformer	87124	JEUMONT	49 (1966)	132/66 - 120MVA	530	Bottom radiator connection gasket worn out	Major	All	9
							Oil pump/connection points	Major	1	
183550	CRANEBROOK ZS No 2 Transformer	70810	TYREE	38 (1977)	33/11kV - 25MVA	70	TX main tank/Cable box interface gasket worn out	Major	Entire	8
							Top and bottom radiator connections gaskets worn out	Major	All	
184141	HAWKESBURY TS No 1 Transformer	70105	TYREE	42 (1973)	132/33kV - 120MVA	1100	132kV Bushing Turrets (A and B phases) gaskets worn out	Major	2	10
							Radiator connections on main bottom manifold pipe	Major	All	
							Built-in main tank tap changer - top gasket worn out	Minor	1	
							Buchholz bleeding oil sampling point small gasket worn out	Minor	1	
							Radiator fins and connections	Minor	Most	
184753	KELLYVILLE ZS No 2	70016	TYREE	46	33/11kV -	240	Top lid gasket worn out	Major	2	7

	Transformer			(1969)	25MVA		Buchholz relay assembly connection	Minor	1	
							Radiator fins and connections	Minor	Most	
184739	KELLYVILLE ZS No 3 Transformer	70017	TYREE	46 (1969)	33/11kV - 25MVA	210	Top lid gasket worn out	Major	Whole front	7
							Buchholz relay assembly connection	Minor	1	
							Radiator fins and connections	Minor	Most	
184306	KINGSWOOD ZS No 1 Transformer	140002	TYREE	32 (1983)	33/11kV - 25MVA	300	Oil leak from RTD box - fixed	Major	1	7
							Top radiator connections gasket worn out	Minor	Most	
183105	LAWSON TS No 1 Transformer (ex no. 3)	78381	LEMELECT	52 (1963)	132/66kV - 52MVA	440	Top and bottom radiator connection gaskets from main manifold pipe worn out	Major	Most	8
							132kV Bushing turret gasket worn out	Major	2	
							Pump connections at manifold pipe	Minor	1	
							Oil drain points	Minor	2	
							Buchholz relay assembly connection	Minor	1	
502372	MT DRUITT TS No 1	26257	TYREE	46 (1969)	132/33kV - 120MVA	250	RTD box gland - Temporarily fixed	Major	1	8
							Pump connections at main tank	Major	1	
							Top lid gasket worn out	Major	4	
							Detached radiator - Top radiator connections at manifold pipe	Major	All	
578378	MT DRUITT TS No 3 Transformer	88205	JEUMONT	47 (1968)	132/33kV - 120MVA	650	Top radiator connection at the main tank (Main manifold pipe)	Major	All	9
							Top hatch gasket worn out	Minor	2	
							Buchholz relay assembly connection	Minor	1	
							Detached radiator - Top radiator connections at manifold pipe	Major	All	
183860	QUAKERS HILL ZS No 1 Transformer	A3T7044/3	ENGLISHE	48 (1967)	132/33kV - 60MVA	350	Top lid gasket worn out	Major	All around	9
							132kV Bushing (B-phase) turret gasket worn out	Major	1	
							33kv Bushing (B-phases)turret gasket worn out	Major	1	
							Main tank radiator pipe bottom connection	Major	1	
187594	ROSEHILL ZS No 1 Transformer	70688	TYREE	41 (1974)	33/11kV - 25MVA	480	Buchholz relay assembly connection	Major	1	8
							Top Radiator connection	Major	Most	
							Top bushing connection or hatches	Major	1	
187569	ROSEHILL ZS No 2 Transformer	70687	TYREE	42 (1973)	33/11kV - 25MVA	320	Buchholz relay assembly connection	Major	1	7
							Oil pump connection (suspected)	Major	1	
							Bottom radiator connection gasket worn out	Major	All	

Appendix F Failure mode and rates for power transformers

Component	Failure	2010			2011		2012		2013		2014			2015		Total	Total	Total
		D	F	C	D	F	D	F	D	F	D	F	C	D	F	D	F	C
AC supply	Supply failed	1							2		3					6		
Breather	Broken	2			2				1							5		
	Low oil								1					1		2		
	Replaced silica gel	24			7		3		15		11			7		67		
	Silica gel replaced										1					1		
Buchholz	Broken	1														1		
	Contacts dirty				1											1		
	Failed						1									1		
	Faulty								1							1		
	Gas alarm	4			5		5		5		3			1		23		
	Oil leak	3			1		1							1		6		
	Oil surge				2		1				2					5		
	Water ingress				1				1		2			1		5		
	Wiring defect	1					1									2		
Bushing	Connection failed		1														1	
	High DDF				2	1										2	1	
	Hot joint	1					1				1					3		
	Noisy	1														1		
	Oil leak								1		1					2		
Conservator	Alarm								1							1		
	Broken				1											1		
	Low oil										1	1				1	1	
	Oil leak	3			2		3		1		4			2		15		

Endeavour Energy

	Rust								1							1		
Control cabinet	Broken													1		1		
	Oil leak				1											1		
	Wiring damage								1							1		
Cooling Control System	Alarm	1			1											2		
	Broken								1							1		
	Failed	3			2		3		2		1					11		
Cover plate	Oil leak	7			5		3		4		2			2		23		
	Rust						1									1		
CT	Failed				1		2									3		
	Oil leak	1														1		
Fans	Broken				1		1									2		
	Controller failed	5			4		6		2		3					20		
	Failed	8			10		15		14		14			3		64		
	Overload	3			3		1				2					9		
	Water ingress													1		1		
	Wiring defect				2				2							4		
Fins	Oil leak	6			1		1		3		4			2		17		
Flow switch	Failed	4														4		
Heater	Failed						2									2		
HV bushing	Cracked									1							1	
	High DDF				1	1						1				1	2	
	Hot joint	1					1		1							3		
	Oil leak	1					1									2		
	Low IR								1							1		

HV cable termination	Failed		1														1	
	Vermin					1											1	
Lightning arrestor	Failed				1			1								1	1	
LV bushing	Broken		1														1	
	Discharged					1											1	
	Hot joint	1							1		1					3		
	Oil leak	1					2									3		
	Replaced					1											1	
Main Tank	Dirty										2					2		
	High oil alarm						1		1							2		
	Low oil								1		1					2		
	Oil leak	60			44		36	2	52	1	42	1		36		270	4	
	Oil leak - TX replaced*									1							1	
	Oil spill	1							1							2		
	Rust						4									4		
	Tighten bolts	1														1		
	High DGA									1							1	
N2 air bag	Leaking	10			7		1		6		3			4		31		
Neutral bushing	Oil leak	2			1											3		
Neutral CT	Failed										2	1				2	1	
Neutral star point	Hot joint								1							1		
OTI	Broken	1														1		
	Failed		1		1		4		4							9	1	
	Oil leak						1									1		

Endeavour Energy

	Vandalism	1														1		
	Water ingress				1											1		
	High temperature alarm						1									1		
Power factor transducers	Failed						1									1		
Pumps	Alarm				2				1							3		
	Controller failed	11			4		2		3		2					22		
	Failed	5			8		9		11		7			1		41		
	Noisy				2		1									3		
	Oil leak				1						1					2		
Sight glass	Broken	2														2		
	Cracked								1							1		
	Dirty						1				1			1		3		
	Oil leak						1				1					2		
Surge arrestor	Failed						1									1		
Tap changer	Alarm				1		3		8		3			2		17		
	Controller failed				12		6		11		6			4	1	39	1	
	Failed				1				1							2		
	Oil leak				9		4		18		13			14		58		
	Silica gel replaced				3				1		2			4		10		
	Vermin													1		1		
	Wiring defect				1		2		1					1		5		
	Breather broken				1						1					2		
	Diverter switch	1					1									2		

	unknown				34		31		16		5			9		95		
	fail to operate (mech)					8		12	1	7		9			11	1	47	
	Contacts					4		4		9		7			6		30	
	Cam Switch					3		2		4		2			4		15	
	Motor box issue				31		22		25		14			12		104		
	Seal failed				6				2					1		9		
	Drive shaft failed					3						2			2		7	
	Sight glass dirty						1							2		3		
Termination Box	Oil leak						1									1		
Transformer	Alarm								1							1		
	Diff trip~		3					1	1	4						1	8	
	Failed									1							1	
	Fault#		2	2				1							1		4	2
	Noisy						1									1		
	Overpressure trip	1				1										1	1	
	Trip~		3		2	4		3		11						2	21	
	Vermin	2														2		
	Lightning trip					1											1	
	Overtemperature trip				1	1										1	1	
	Diff trip replaced TX#											1					1	

Endeavour Energy

	High temperature alarm	1			3		1		2							7		
	High gas replaced TX@					1											1	
	Removal#										2		1			2		1
	Self-energised				1											1		
	Earth fault trip							1									1	
Voltage regulator	Contacts dirty				1											1		
	Failed				1		2									3		
VT	Failed						1									1		
	Wiring defect				1											1		
Windings	Connection failed		1														1	
	High DDF$	1	1													1	1	
	Hot joint				2											2		
	Short circuit%		1	1													1	1
	Low IR				1											1		
WTI	Broken								2							2		
	Fail alarm								1							1		
	Failed	1			1											2		
	Not calibrated				1											1		
	Oil leak				1											1		
	Vermin								1							1		
	Water ingress								1							1		

	Wiring defect						1		1							2		
Stand off insulator	Failed								1		3	1				4	1	
Breathers	Low oil													1		1		
	Oil leak													1		1		
Pressure release valve	Failed				1		2									3		
Earthing	Wiring defect						1									1		
TOTAL		184	15	**3**	244	31	199	27	239	40	167	26	**1**	116	25	1149	164	**4**

~ Cause of trip is not specified in Ellipse data.

Transformer replaced due to electrical fault (failed component unknown, but assumed to be winding failure).

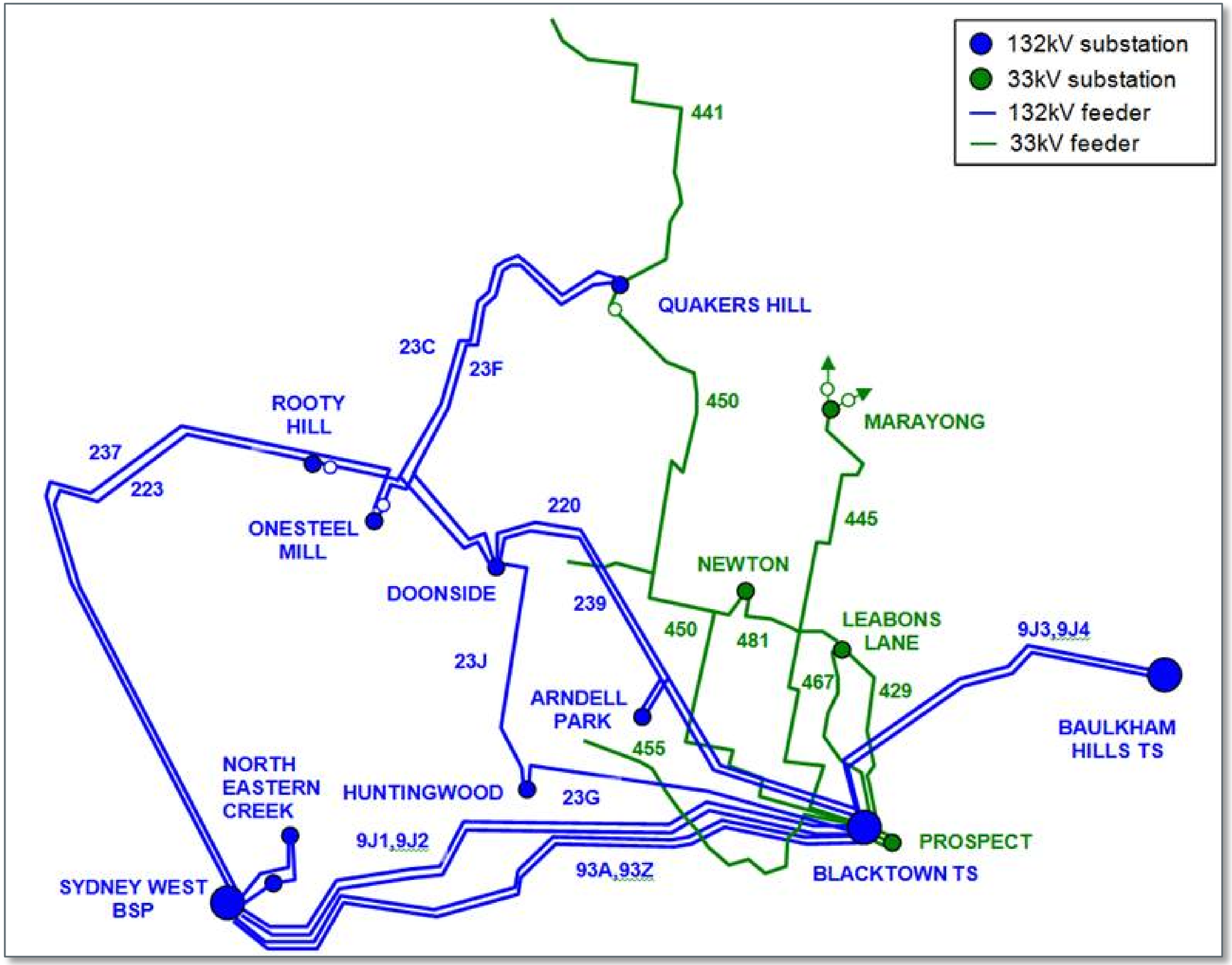
$ *Transformer replaced due to poor winding DDF results.*

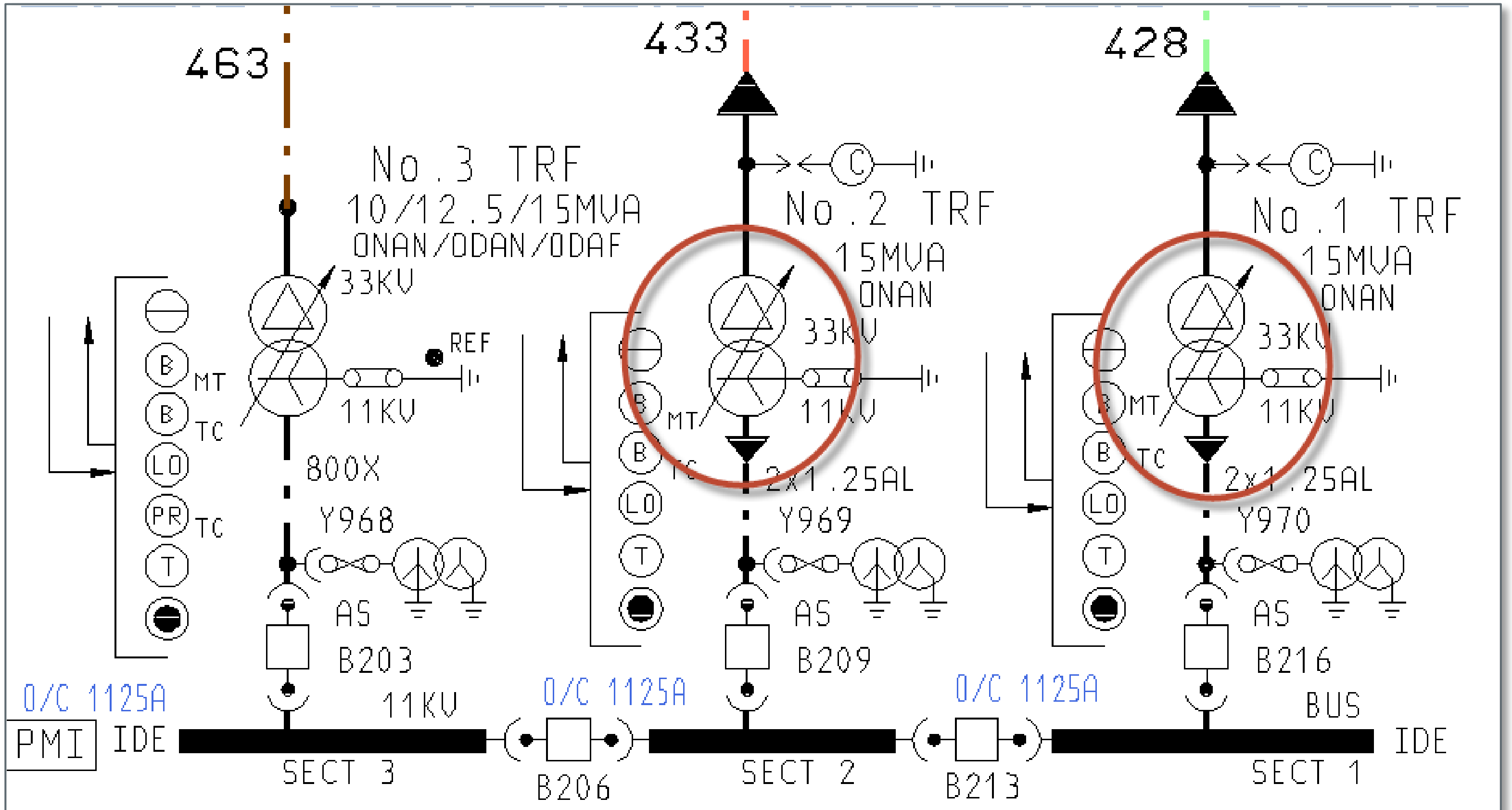
% Transformer replaced due to winding insulation failure caused by fault.

@ *Transformer replaced due to high DGA results after fault occurred, was not in service at the time.*

* Transformer replaced due to major oil leaks, was not in service at the time.

APPENDIX B : PROSPECT ZS SUPPLY ARRANGEMENTS





PROSPECT

505

MS/STU

Tx RATING	10/12.5/15MVA
33kV CABLES	=Tx
11kV CABLES	=Tx
33kV O/C	500A/28MVA
11kV O/C	1125A/21MVA
11kV BAR	2000A/38MVA
WINDING TEMPERATURE	130

Ellipse Login | Load Estimates | Retrieve Actuals | Copy to Project Directory | Clear Log

PROJECT:

Project Description:

TOTALS	Work Packet	Labour Cost	Actual	Store Costs	Actual	Plant Costs	Actual	Direct Charge	Actual	Total Costs	Total Actual	Contingency		Reason For Contingency
Planning & Development	1	$ 50,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 50,000	$ -	$ -	0%	
NIOs & PDs	1.1	$ 25,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 25,000	$ -	$ -		
Environmental Requirements	1.2	$ 25,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 25,000	$ -	$ -		
Substation Design	2	$ 42,946	$ -	$ -	$ -	$ -	$ -	$ 15,000	$ -	$ 57,946	$ -	$ 1,738	3%	
Electrical, Mechanical & Civil	2.1	$ 32,946	$ -	$ -	$ -	$ -	$ -	$ 15,000	$ -	$ 47,946	$ -	$ 1,438		3 % for design modifications
Architect	2.2	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -		
Earthing Design	2.3	$ 10,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 10,000	$ -	$ 300		3 % for design modifications
Project Management	3	$ 90,000	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 90,000	$ -	$ -	0%	
Substation Procurement / Subcontract	4	$ 6,091	$ -	$ 18,050	$ -	$ 6,822	$ -	$ 1,503,043	$ -	$ 1,534,006	$ -	$ 13,343	1%	
Major Equipment	4.1	$ -	$ -	$ -	$ -	$ 1,409	$ -	$ 1,377,600	$ -	$ 1,379,009	$ -	$ -		
Minor Equipment	4.2	$ -	$ -	$ 13,178	$ -	$ 3,275	$ -	$ 45,000	$ -	$ 61,453	$ -	$ 9,218		Allow 5 % per year for copper & foreign exchange
Steelwork & Busbars/Fittings	4.3	$ -	$ -	$ 4,292	$ -	$ 1,571	$ -	$ 21,638	$ -	$ 27,501	$ -	$ 4,125		Allow 5 % per year for steel prices
Major Equipment Storage	4.4	$ -	$ -	$ -	$ -	$ -	$ -	$ 42,678	$ -	$ 42,678	$ -	$ -		
On Site Security	4.5	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -		
Landscaping	4.6	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -		
Control Panels	4.7	$ 6,091	$ -	$ 580	$ -	$ 175	$ -	$ 3,500	$ -	$ 10,346	$ -	$ -		
SCADA Hardware	4.8	$ -	$ -	$ -	$ -	$ 94	$ -	$ 2,063	$ -	$ 2,157	$ -	$ -		
Protection Relays	4.9	$ -	$ -	$ -	$ -	$ 298	$ -	$ 10,564	$ -	$ 10,862	$ -	$ -		
Trans Subs Construction	5	$ 95,378	$ -	$ 743	$ -	$ 2,020	$ -	$ -	$ -	$ 98,141	$ -	$ -	0%	
Electrical Works	5.1	$ 70,625	$ -	$ 743	$ -	$ 1,483	$ -	$ -	$ -	$ 72,851	$ -	$ -		
Protection & Control	5.2	$ 23,306	$ -	$ -	$ -	$ 440	$ -	$ -	$ -	$ 23,746	$ -	$ -		
HV Test	5.3	$ 1,447	$ -	$ -	$ -	$ 98	$ -	$ -	$ -	$ 1,544	$ -	$ -		
Metering	5.4	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -		
Trans Mains Construction	6	$ 60,434	$ -	$ -	$ -	$ 123,789	$ -	$ 164,942	$ -	$ 349,165	$ -	$ 34,917	10%	
Project Management & Design	6.1	$ 60,434	$ -	$ -	$ -	$ -	$ -	$ 38,942	$ -	$ 99,376	$ -	$ 9,938		10 % for design modifications
Survey	6.2	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -		
Civil Works	6.3	$ -	$ -	$ -	$ -	$ -	$ -	$ 96,000	$ -	$ 96,000	$ -	$ 9,600		10 % for delays
Material Procurement	6.4	$ -	$ -	$ -	$ -	$ 123,789	$ -		$ -	$ 123,789	$ -	$ 12,379		10 % for design modifications/variations
Construction	6.5	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -		
Restorations	6.6	$ -	$ -	$ -	$ -	$ -	$ -	$ 30,000	$ -	$ 30,000	$ -	$ 3,000		10 % for variations
Distribution Construction	7	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	0%	
Civil & Building Works	8	$ 1,287	$ -	$ 434	$ -	$ -	$ -	$ 890,810	$ -	$ 892,531	$ -	$ 258,506	29%	Allow 20 % for contaminated soil or rock + $80k for removal of asbestos
Additional Costs:	9	$ -	$ -	$ -	$ -	$ -	$ -	$ 170,000	$ -	$ 170,000	$ -	$ -	0%	
Changeover	9.1	$ -		$ -		$ -				$ -		$ -		
Disposal/Demolision	9.2	$ -		$ -		$ -		$ 60,000		$ 60,000		$ -		
Air box modification	9.3	$ -		$ -		$ -		$ 50,000		$ 50,000		$ -		
Supervision/ Site Cordinator	9.4	$ -		$ -		$ -		$ 30,000		$ 30,000		$ -		
Relocation of Mast/Earth Study	9.5	$ -		$ -		$ -		$ 30,000		$ 30,000		$ -		
	9.6	$ -		$ -		$ -		$ -		$ -		$ -		
	9.7	$ -		$ -		$ -		$ -		$ -		$ -		
	9.8	$ -		$ -		$ -		$ -		$ -		$ -		
	9.9	$ -		$ -		$ -		$ -		$ -		$ -		
Totals		$ 346,136	$ -	$ 19,227	$ -	$ 132,631	$ -	$ 2,743,795	$ -	$ 3,241,790	$ -	$ 308,504	10%	

Assumed CPI = 2.5%

	YEAR					
	1st	2nd	3rd	4th	5th	Total
% Spend	28 %	72 %	0 %	0 %	0 %	100 %
Cost Breakdown	$ 907,701	$ 2,334,089	$ -	$ -	$ -	$ 3,241,790
CPI	$ -	$ 58,352	$ -	$ -	$ -	$ 58,352

= Assume no CPI for 1st Year

= Only change percentages

Total (inc CPI): $ 3,300,000

Contingency: $ 300,000

Endeavour Energy

APPENDIX E : NOISE REPORT

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ENVIRONMENTAL NOISE IMPACT

PROSPECT ZONE SUBSTATION

AT PROSPECT, NSW

REPORT NUMBER: **4520**

PREPARED FOR: Integral Energy Pty Ltd
PO Box 6366
Blacktown NSW 2148

Attention: Ms Pat Woodbury
Telephone: 9853 6552

DATE ISSUED: 25 January 2011

Report Status	**Prepared by:** William Wang	**Approved by:** Stephen Gauld
Final		

Document R\4520-r1, 12 pages plus attachments

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1.0 CONSULTING BRIEF

Day Design Pty Ltd was engaged by Integral Energy Pty Ltd to investigate the environmental noise impact of their proposed upgrade to Prospect Zone Substation at Prospect, NSW. This commission involves the following:

Scope of Work:

- Inspect the site and environs.
- Measure the background noise levels at critical locations and times.
- Establish the acceptable noise level criteria.
- Quantify noise emissions from the Zone Substation.
- Calculate the level of noise emission, taking into account building envelope transmission loss, screen walls and distance attenuation.
- Prepare a site plan identifying the development and nearby noise sensitive locations.
- Provide reasonable and feasible recommendations for noise control (if necessary).
- Prepare an Environmental Noise Impact Report.

2.0 PROJECT DESCRIPTION & SUMMARY OF FINDINGS

Integral Energy supplies electricity to the greater part of Sydney's west, the Blue Mountains, the Illawarra and Southern Highlands regions. To sustain this service they have a number of Substations to convert high voltage electricity to standard 240 volt supply. The transformers used for the conversion typically generate a low frequency ‘hum’ at 100 Hz.

The Prospect Zone Substation currently has three existing 33 kV / 11 kV, 15 MVA transformers. It is intended to remove one of the existing 33 kV / 11 kV, 15 MVA from the site and installing a new 33 kV / 11 kV, 15 MVA at a different location.

The nearest potentially affected residences are adjacent to the south of the site. More residential premises are located to the east of the site, on the other side of Blacktown Road. Commercial properties lie to the west of the site. Ambient background noise measurements were carried out in a nearby residential area with the results detailed in Section 4.

Noise control measures have been recommended in Section 7 of this report to reduce the noise emission from the existing transformers as well as the proposed upgrade at the Prospect Zone Substation to comply with the Department of Environment, Climate Change and Waters’ Industrial Noise Policy environmental noise guidelines.

3.0 NOISE SURVEY INSTRUMENTATION

Noise level measurements and analysis were made with sound instrumentation as follows:

Table 3.1 Noise Instrumentation

Description	Model No.	Serial No.
Modular Precision Sound Analyser	B&K 2250	2611644
Condenser Microphone 0.5” diameter	B&K 4189	2607875
Acoustical Calibrator	B&K 4231	2095415
Microphone Windscreen	Acoustically transparent foam	
Infobyte Noise Logger	iM4	106
Condenser Microphone 0.5” diameter	MK 250	106
Microphone Windscreen	Acoustically transparent foam	

The **B&K 2250 Sound Analyser** is a real-time precision integrating sound level meter with octave and third octave filters that samples noise at a rate of 10 samples per second. The B&K 2250 provides L_{eq}, L_1, L_{10}, L_{50} and L_{90} statistical data at 15 minute intervals (longer or shorter intervals optional) over the desired monitoring period. Results are normally downloaded to computer for rapid processing.

An environmental noise logger is used to continuously monitor ambient noise levels and provide information on the statistical distribution of noise during an extended period of time. The Infobyte Noise Monitor iM4 is a Type 2 precision environmental noise monitor meeting all the applicable requirements of AS1259 for an integrating-averaging sound level meter.

All instrument systems had been laboratory calibrated using instrumentation traceable to Australian National Standards and certified within the last two years thus conforming to Australian Standards. The measurement system was also field calibrated prior to and after noise surveys. Calibration drift was found to be less than 0.3 dB during attended measurements and within 1 dB for long-term measurements. No adjustments for instrument drift during the measurement period were warranted.

4.0 MEASURED AMBIENT NOISE LEVELS

In order to assess the severity of a possible environmental noise problem in a residential area it is necessary to measure the ambient background noise level at the times and locations of worst possible annoyance. The lower the background noise level, the more perceptible the intrusive noise becomes and the more potentially annoying.

The ambient L_{90} background noise level is a statistical measure of the sound pressure level that is exceeded for 90% of the measuring period (typically 15 minutes).

The Rating Background Level (RBL) is defined by the Department of Environment, Climate Change and Water as the median value of the (lower) tenth percentile of L_{90} ambient background noise levels for day, evening or night periods, measured over 7 days during the proposed days and times of operation (EPA, 2000).

Ambient L_{90} background noise levels were measured at Location "A" shown on the Site Plan over seven (7) days from Friday 12 November 2010 to Thursday 18 November 2010. This location was selected to represent an equivalent background noise level in the absence of the Zone Substation. Measuring too close to the Zone Substation will cause the measured background noise level to include transformer noise which is undesirable. The measured levels are presented in the attached Figure 2 and also in Table 4.1 below.

Table 4.1 Rating Background Level

Noise Measurement Location	Time Period	Rating Background Level
Location 'A' – 17 Fox Hills Crescent, Prospect, NSW	Day (7am to 6 pm)	**44 dBA**
	Evening (6 pm to 10 pm)	**42 dBA**
	Night (10 pm to 7 am)	**38 dBA**

Meteorological conditions during the testing typically consisted of clear skies with temperatures of 12 to 30 ^{o}C. Atmospheric conditions were ideal for noise monitoring. Noise measurements were therefore considered reliable and typical for the receptor area.

5.0 ACCEPTABLE NOISE LEVELS

5.1 NSW Industrial Noise Policy

The Environment Protection Authority published their NSW Industrial Noise Policy (EPA, 2000) in January 2000. The Environment Protection Authority has since been amalgamated with a number of other State Government departments into the Department of Environment, Climate Change and Water (DECCW). The Industrial Noise Policy is specifically aimed at assessing noise from industrial noise sources scheduled under the Protection of the Environment Operations Act 1997 (POEO, 1997).

Prospect Zone Substation is not a ‘scheduled premises’ under the Protection of the Environment Operations Act 1997 as Integral Energy Pty Ltd is not required to hold a licence under that Act for operations at the site.

The appropriate regulatory authority (DECCW) may, by notice in writing given to such a person, prohibit the person from causing, permitting or allowing:

any specified activity to be carried on at the premises, or

(a) any specified article to be used or operated at the premises,

or both, in such a manner as to cause the emission from the premises, at all times or on specified days, or between specified times on all days or on specified days, of noise that, when measured at any specified point (whether within or outside the premises,) is in excess of a specified level.

It is an offence to contravene a noise control notice. Prior to being issued with a noise control notice, no offence has been committed.

The Industrial Noise Policy provides a useful framework to assess noise emission from non-scheduled premises, whether that premises produces offensive or non-offensive noise.

The Protection of the Environment Operations Act 1997 defines “Offensive Noise” as noise:

(a) that, by reason of its level, nature, character or quality, or the time at which it is made, or any other circumstances:
   (i) is harmful to (or is likely to be harmful to) a person who is outside the premises from which it is emitted, or
   (ii) interferes unreasonably with (or is likely to interfere unreasonably with) the comfort or repose of a person who is outside the premises from which it is emitted, or
(b) that is of a level, nature, character or quality prescribed by the regulations or that is made at a time, or in other circumstances prescribed by the regulation.

While the Industrial Noise Policy is not strictly applicable to this site, as the site is not scheduled, in the absence of other relevant standards the limits set out in the NSW Industrial

Noise Policy will be used as a guide in determining whether the level of noise is and will be considered offensive or not.

5.2 Residential Receptor Noise Intrusiveness Criteria

The DECCW states in Section 2.1 of its NSW Industrial Noise Policy (January 2000) that the L_{eq} level of noise intrusion from broad-band industrial noise sources may be up to 5 dBA above the L_{90} background noise level at the receptor without being considered offensive (EPA, 2000, Section 2.1).

The Rating Background Level at Prospect was 44 dBA during the daytime, 42 dBA in the evening and 38 dBA at night. Therefore the acceptable L_{eq} noise intrusiveness criterion for broadband noise in this area is:

- (44 + 5 =) 49 dBA during the day,
- (42 + 5 =) 47 dBA in the evening and
- (38 + 5 =) 43 dBA at night.

Where a noise source contains certain characteristics, such as tonality, impulsiveness, intermittency or dominant low-frequency content, there is evidence to suggest that it can cause greater annoyance than other noise at the same noise level. Correction factors may be applied to the noise intrusiveness criteria to determine the project specific criteria.

The tonality and low frequency modifying factors are potentially applicable to the assessment and are presented in the attached Datasheet AC 500-9.

Therefore the acceptable L_{eq} noise intrusiveness criterion for tonal and/or low frequency noise in this area is:

- (44 + 5 -5 =) 44 dBA during the day,
- (42 + 5 -5 =) 42 dBA in the evening and
- (38 + 5 -5 =) 38 dBA at night.

5.3 Project Specific Noise Criteria

When all the above factors are considered, we find that the most stringent noise criterion is:

- **49 dBA for broadband,** and **44 dBA for tonal noise sources** during the day,
- **47 dBA for broadband,** and **42 dBA for tonal noise sources** in the evening,
- **43 dBA for broadband** and **38 dBA for tonal noise sources** at night.

These criteria apply at the most-affected point on or within the residential property boundary – or, if that is more than 30 metres from the residence, at the most-affected point within 30 metres of the residence. For upper floors, the noise is assessed outside the nearest window.

6.0 PROSPECT ZONE SUBSTATION NOISE EMISSION

The main sources of noise from the Prospect Zone Substation are the transformers that operate continually throughout the day and night. The noise level does not change appreciably from the day to the night and therefore the noise level at night will be the worst-case scenario.

6.1 Sound Power Levels

The writer visited the site on Tuesday 7 December 2010 to measure the noise level and character from the existing high voltage transformers and capacitor banks at the Prospect Zone Substation.

Tonal components are shown in bold, typically at 100 Hz and a harmonic at 200 Hz.

Table 6.1 Transformer L_{eq} Sound Power Levels

Description	Sound Power Levels (dB) at Third Octave Band Centre Frequencies (Hz)							
	dBA	50 63 80	100 125 160	200 250 315	400 500 630	800 1k 1k25	1k6 2k 2k5	3k15 4k 5k
No 1 Transformer 33 kV / 11kV, 15 MVA (existing / standby)	***86***[1]	*74 75 78*	***94*** *76 75*	***95*** *77 83*	*74 68 69*	*69 65 61*	*56 56 53*	*52 50 50*
No 2 Transformer 33 kV / 11 kV, 15 MVA (existing)	***86***[1]	*74 75 78*	***94*** *76 75*	***95*** *77 83*	*74 68 69*	*69 65 61*	*56 56 53*	*52 50 50*
No 3 Transformer 33 kV / 11 kV, 15 MVA (existing)	***92***[1]	*72 74 76*	***92*** *75 82*	***103*** *84 75*	*77 72 77*	*73 71 68*	*66 66 63*	*62 62 64*
Transformer 33 kV / 11 kV, 15 MVA (proposed)	**76**[2]	76 77 75	86 72 64	77 63 67	63 75 70	69 57 56	54 52 50	49 45 41
Capacitor 1	**75**	71 72 71	70 65 67	**85** 67 71	63 58 58	56 56 55	53 51 51	50 49 49
Capacitor 3	**73**	71 75 73	75 65 65	**81** 64 67	59 61 67	59 57 55	54 52 51	50 48 47
Typical Cooling Fan	**70***	65	60	64	65	66	63	61

[1] Approximately 60% load operating condition (~ 9 MVA)

[2] Sound power level at 66% load operating condition

*Cooling fan noise level data have been taken from a typical fan manufacturer's data.

Transformer No. 1 was not operating (on standby) at the time of measurement. From the age and specification of the transformers, it is assumed that the sound power level of Transformer No. 1 is the same as Transformer No. 2.

Knowing the sound power level of a noise source (see above Table 6.1), the sound pressure level (as measured with a sound level meter) can be calculated at a remote location using suitable formulae to account for distance losses, sound barriers, etc.

6.2 Existing Noise Levels

The Prospect Zone Substation site at Prospect currently has two capacitor banks and three 33 kV / 11 kV, 15 MVA transformers, of which one is designated as a reserve (not energised). Normal operating conditions for this substation is for 2 transformers operating at any one time. The worst case has been modelled with three transformers and two capacity banks all operational.

The calculated sound pressure level at the nearest residential premises due to the existing configuration of the Zone Substation is as shown in Table 6.2, below.

Table 6.2 Calculated Existing Sound Pressure Levels at Receptor Locations

Receptor Location	Calculated L_{eq} Noise Level	Tonal	Acceptable L_{eq} Noise Level	Compliance
Location 'B' – Residential 436 Blacktown Road, Prospect	58 dBA	Yes	38 dBA	**NO** **20 dB excess**
Location 'C' – Residential 9 Fox Hills Crescent, Prospect	47 dBA	No*	43 dBA	**NO** **4 dB excess**
Location 'D' – Residential 422 Blacktown Road, Prospect	49 dBA	No*	43 dBA	**NO** **6 dB excess**

*An ambient noise survey was conducted during the night. The ambient noise was found to have masked the tonal components and thus be non-tonal at the receptor.

Integral Energy proposes to decommission one 33 kV / 11 kV, 15 MVA transformer and replace it with a new 33 kV / 11 kV, 15 MVA transformer at a new location.

The calculated existing level of noise due to the existing Prospect Zone Substation exceeds the acceptable at two nearby residential receptors. Noise control treatment will be required as recommended in Section 7 of this report.

7.0 NOISE CONTROL RECOMMENDATIONS

The existing level of noise emission from the Prospect Zone Substation is above the recommended noise limits established in Section 5.0 of this report. Therefore engineering noise control will be required. We recommend the following acoustical treatment.

7.1 Option 1 – Masonry Barrier

Option 1 consists of (refer to attached Figure 3):

- Solid 4.5 metre high masonry barrier on the southern boundary of the Zone Substation
- Solid 8 metre high masonry barrier on the southern side of transformers 1 and 2. The masonry barriers should have absorptive insulation installed on the side facing the transformers barrier to reduce reflected noise. The sound absorptive insulation should consist of 100 mm rockwool insulation (density 30 kg/m^3) fitted between 100 mm deep battens or purlins and faced with perforated galvanised steel (open area 20%).

7.2 Option 2 – 'Low Noise' Transformers

To avoid acoustic barriers, it is recommended to replace all three existing transformers with new transformers that have a maximum sound power level of 76 dBA at 66% load (70 dBA at no load). With this recommendation, the level of noise at the nearby residential receptors will meet the acceptable noise criteria specified in Section 5.0 without the need for any solid sound barriers.

7.3 Construction Disclaimer

Recommendations made in this report are intended to resolve acoustical problems only. We make no claim of expertise in other areas and draw your attention to the possibility that our recommendations may not meet the structural, fire, thermal or other aspects of building construction.

We encourage clients to check with us before using materials or equipment that are alternative to those specified in our Acoustical Report.

8.0 PREDICTED NOISE LEVELS AT RECEPTOR LOCATIONS

Assuming either of the recommendations of Section 7.0 has been satisfactorily implemented, the resultant intrusive L_{eq} noise levels at various receptor locations is calculated to be as shown below in Tables 8.1 and 8.2.

Table 8.1 Option 1 Predicted Sound Pressure Levels at Receptor Locations
(After Section 7.1 noise controls have been implemented)

Receptor Location	Calculated L_{eq} Noise Level	Tonal	Acceptable L_{eq} Noise Level	Compliance
Location 'B' – Residential 436 Blacktown Road, Prospect	38 dBA	Yes	38 dBA	**Yes**
Location 'C' – Residential 9 Fox Hills Crescent, Prospect	40 dBA	No*	43 dBA	**Yes**
Location 'D' – Residential 422 Blacktown Road, Prospect	42 dBA	No*	43 dBA	**Yes**

*an ambient noise survey was conducted during the night. The ambient noise was found to have masked the tonal components and thus be non-tonal at the receptor.

Table 8.2 Option 2 Predicted Sound Pressure Levels at Receptor Locations
(After Section 7.2 noise controls have been implemented)

Receptor Location	Calculated L_{eq} Noise Level	Tonal	Acceptable L_{eq} Noise Level	Compliance
Location 'B' – Residential 436 Blacktown Road, Prospect	42 dBA	No	43 dBA	**Yes**
Location 'C' – Residential 9 Fox Hills Crescent, Prospect	36 dBA	No	43 dBA	**Yes**
Location 'D' – Residential 422 Blacktown Road, Prospect	38 dBA	No	43 dBA	**Yes**

9.0 NOISE IMPACT STATEMENT

Measurements and computations show that, provided either of the recommendations made in Section 7 of this report is satisfactorily implemented, the level of noise emitted by the proposed upgrade to the Prospect Zone Substation will meet the Environment Protection Authority's acceptable noise level requirements as detailed in Section 5.0 of this report.

We are of the opinion that sound emitted from this development will not cause “offensive noise” as defined by the Protection of the Environment Operations Act 1997.

William Wang, BE (Mechatronics), MAAS

Consulting Acoustical Engineer

for and on behalf of Day Design Pty Ltd.

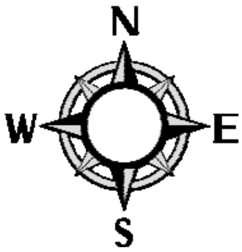
A.A.A.C. MEMBERSHIP

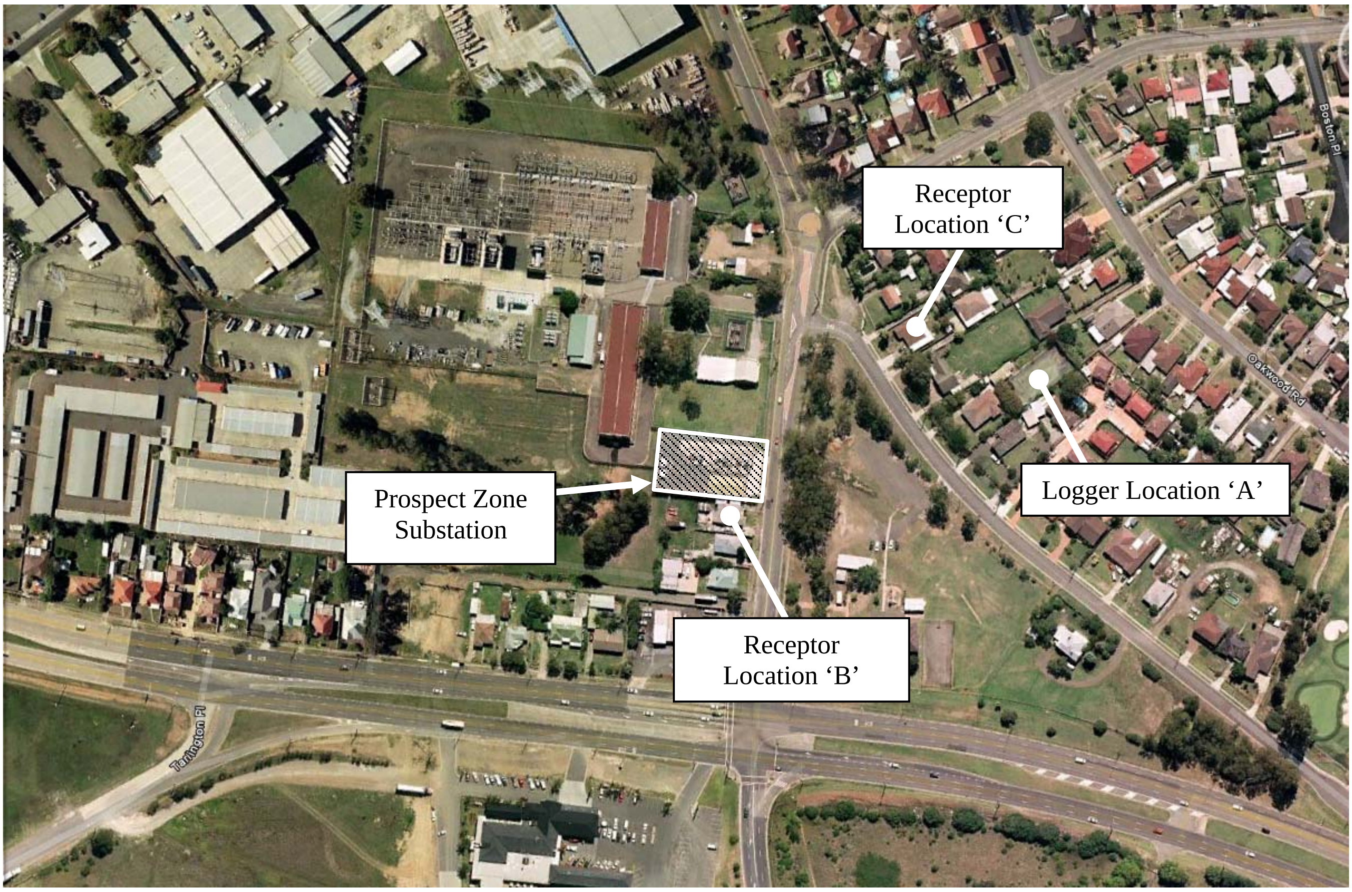
Day Design Pty Ltd is a member company of the Association of Australian Acoustical Consultants, and the work herein reported has been performed in accordance with the terms of membership.

Attachments:

- Figure 1 – Location Plan
- Figure 2 – Ambient Noise Survey
- Figure 3 – Proposed General Arrangement
- Figure 4 – Barrier Locations
- AC 108-1 to 4 – Glossary of Acoustic Terms
- AC 500-9 – Modifying Factor Correction

DAY DESIGN	**Prospect Zone Substation** **Site Location Plan**	**4520** **FIGURE 1**

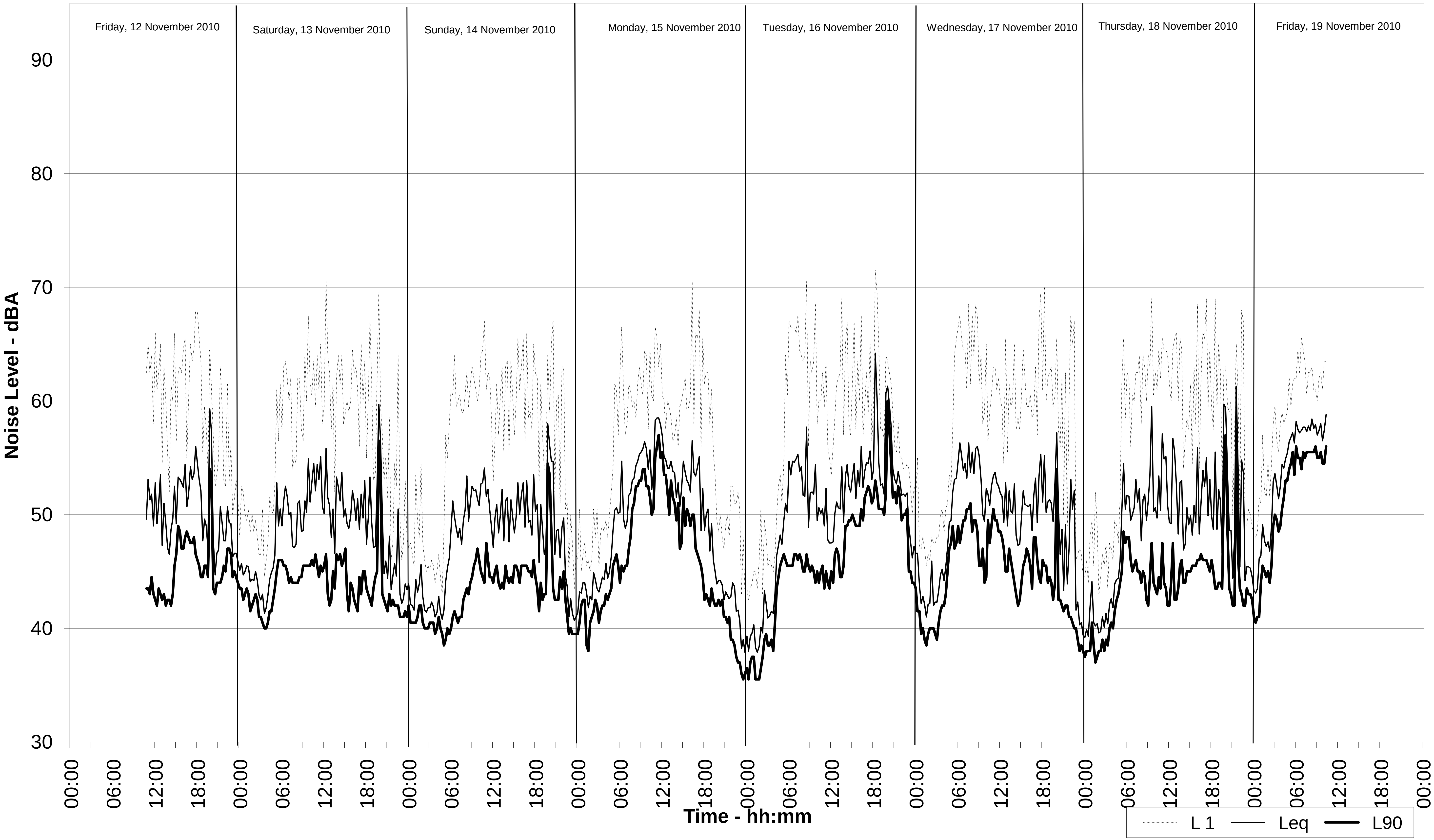




Report 4520
Figure 2

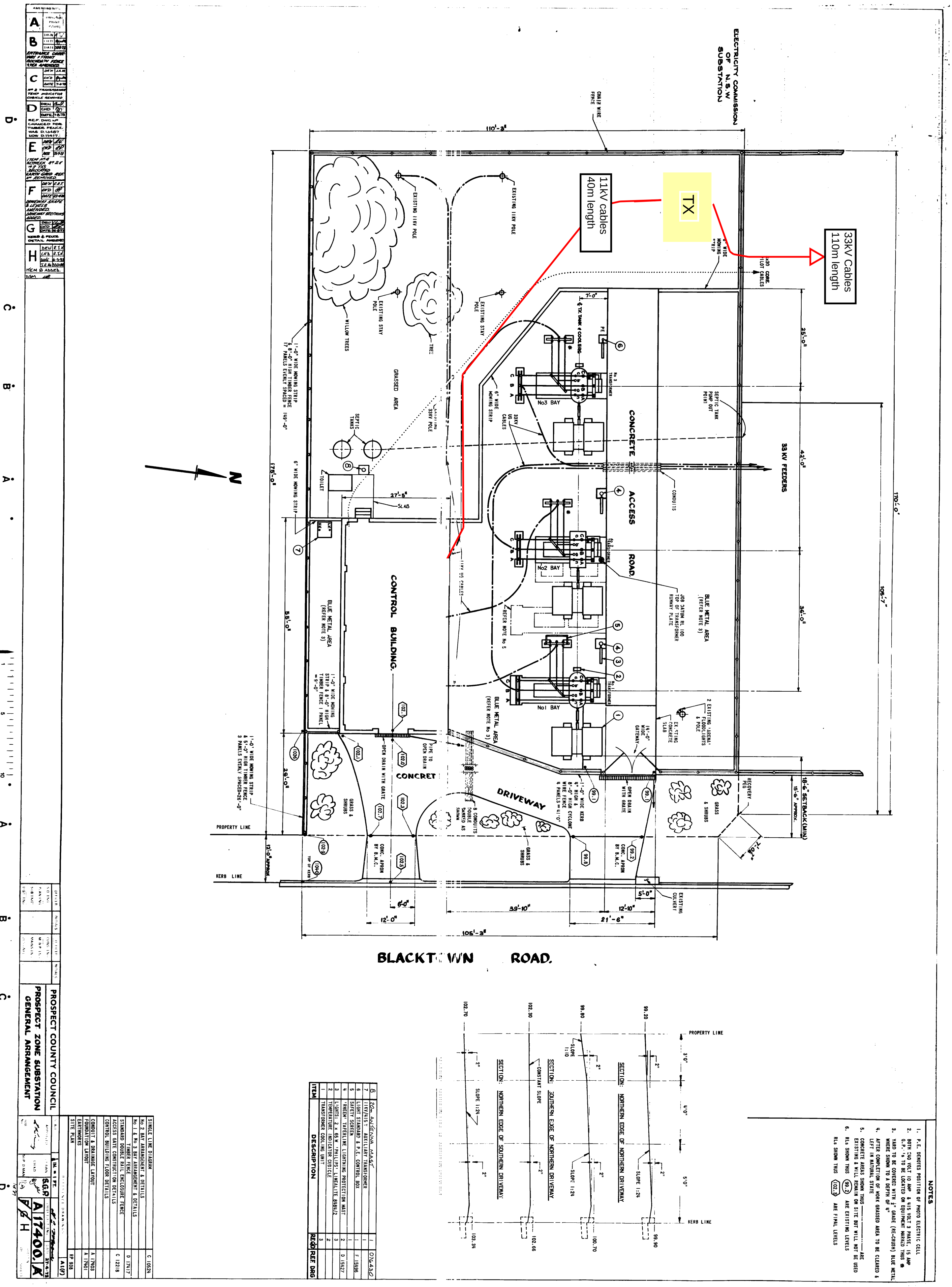
Ambient Noise Survey

Located at 17 Fox Hills Crescent, Prospect, NSW

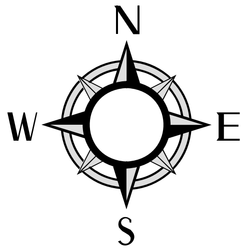


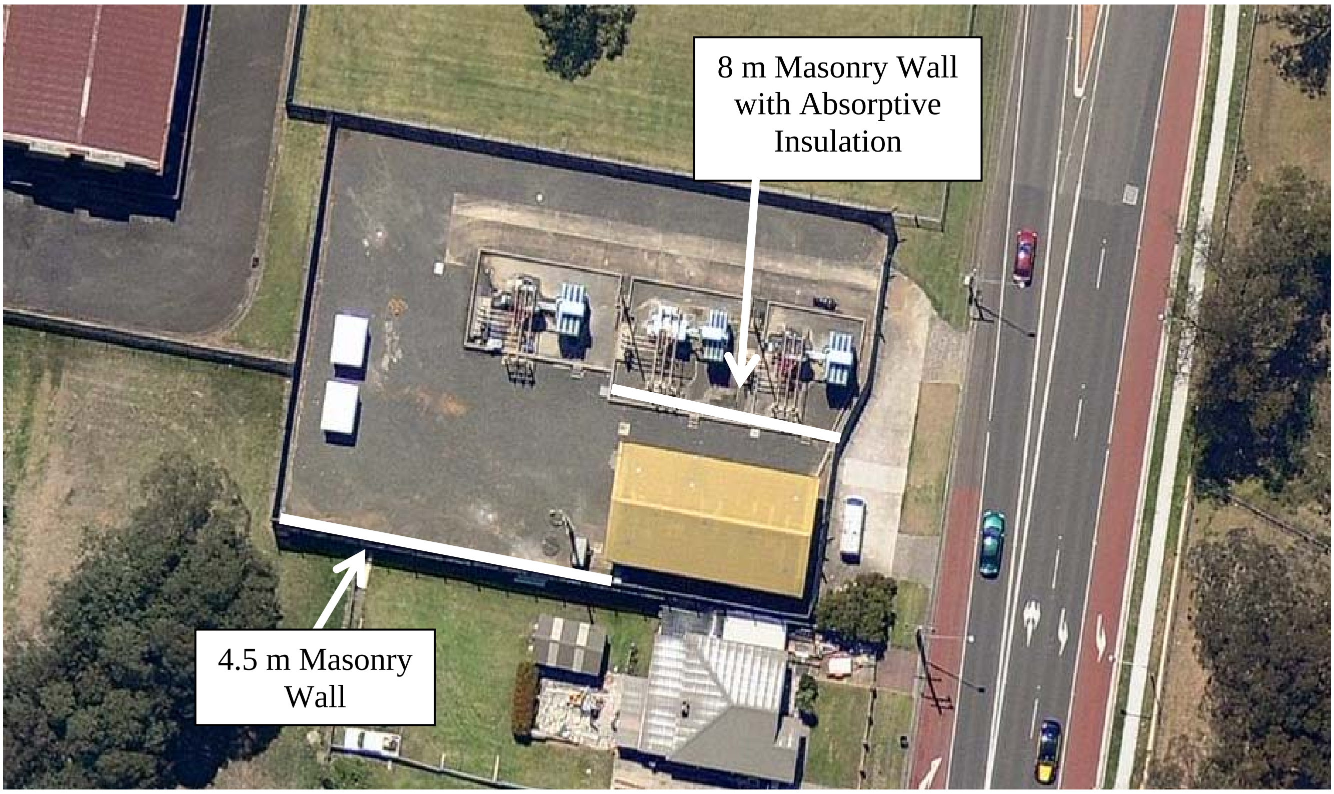
DAY DESIGN PTY LTD

4520 Figure 3



DAY DESIGN	Prospect Zone Substation Barrier Location	4520 FIGURE 4





ACOUSTICAL – Pertaining to the science of sound, including the generation, propagation, effects and control of both noise and vibration.

AMBIENT NOISE – The ambient noise level at a particular location is the overall environmental noise level caused by all noise sources in the area, both near and far, including road traffic, factories, wind in the trees, birds, insects, animals, etc.

AUDIBLE – means that a sound can be heard. However, there are a wide range of audibility grades, varying from "barely audible" to "just audible", "clearly audible" and "prominent". Chapter 83 of the NSW Environment Protection Authority – Environmental Noise Control Manual (1985) states:

"noise from a particular source might be offensive if it is clearly audible, distinct from the prevailing background noise and of a volume or character that a reasonable person would be conscious of the intrusion and find it annoying or disruptive".

It follows that the word "audible" in an environmental noise context means "clearly audible".

BACKGROUND NOISE LEVEL – Silence does not exist in the natural or the built-environment, only varying degrees of noise. The Background Noise Level is the average minimum dBA level of noise measured in the absence of the noise under investigation and any other short-term noises such as those caused by cicadas, lawnmowers, etc. It is quantified by the L_{A90} or the dBA noise level that is exceeded for 90 % of the measurement period (usually 15 minutes).

- **Assessment Background Level (ABL)** is the single figure background level representing each assessment period – day, evening and night (i.e. three assessment background levels are determined for each 24hr period of the monitoring period). Determination of the assessment background level is by calculating the tenth percentile (the lowest tenth percent value) of the background levels (L_{A90}) for each period (Refer: NSW Industrial Noise Policy, 2000).
- **Rating Background Level (RBL)** as specified by the Environment Protection Authority is the overall single figure (L_{A90}) background noise level representing an assessment period (day, evening or night) over a monitoring period of (normally) three to seven days.

  The RBL for an assessment period is the median of the daily lowest tenth percentile of L_{90} background noise levels.

  If the measured background noise level is less than 30 dBA, then the Rating Background Level (RBL) is considered to be 30 dBA.

DECIBEL – The human ear has a vast sound-sensitivity range of over a thousand billion to one. The decibel is a logarithmic unit that allows this same range to be compressed into a somewhat more comprehensible range of 0 to 120 dB. The decibel is ten times the logarithm of the ratio of a sound level to a reference sound level. See also Sound Pressure Level and Sound Power Level.

Decibel noise levels cannot be added arithmetically since they are logarithmic numbers. If one machine is generating a noise level of 50 dBA, and another similar machine is placed beside it, the level will increase to 53 dBA, not 100 dBA. Ten similar machines placed side by side increase the sound level by 10 dBA, and one hundred machines increase the sound level by 20 dBA.

dBC – The dBC scale of a sound level meter is similar to the dBA scale defined above, except that at high sound intensity levels, the human ear frequency response is more linear. The dBC scale approximates the 100 phon equal loudness contour.

dBA – The human ear is less sensitive to low frequency sound than high frequency sound. We are most sensitive to high frequency sounds, such as a child's scream. Sound level meters have an inbuilt weighting network, termed the dBA scale, that approximates the human loudness response at quiet sound levels (roughly approximates the 40 phon equal loudness contour).

However, the dBA sound level provides a poor indication of loudness for sounds that are dominated by low frequency components (below 250 Hz). If the difference between the "C" weighted and the "A" weighted sound level is 15 dB or more, then the NSW Industrial Noise Policy recommends a 5 dBA penalty be applied to the measured dBA level.

EQUIVALENT CONTINUOUS NOISE LEVEL, L_{Aeq} – Many noises, such as road traffic or construction noise, vary continually in level over a period of time. More sophisticated sound level meters have an integrating electronic device inbuilt, which average the A weighted sound pressure levels over a period of time and then display the energy average or L_{Aeq} sound level. Because the decibel scale is a logarithmic ratio the higher noise levels have far more sound energy, and therefore the L_{Aeq} level tends to indicate an average which is strongly influenced by short term, high level noise events. Many studies show that human reaction to level-varying sounds tends to relate closely to the L_{Aeq} noise level.

FREE FIELD – This is a sound field not subject to significant reflection of acoustical energy. A free field over a reflecting plane is usually outdoors with the noise source resting on hard flat ground, and not closer than 6 metres to any large flat object such as a fence or wall; or inside an anechoic chamber.

FREQUENCY – The number of oscillations or cycles of a wave motion per unit time, the SI unit being the Hertz, or one cycle per second.

IMPACT ISOLATION CLASS (IIC) – The American Society for Testing and Materials (ASTM) has specified that the IIC of a floor/ceiling system shall be determined by operating an ISO 140 Standard Tapping Machine on the floor and measuring the noise generated in the room below. The IIC is a number found by fitting a reference curve to the measured octave band levels and then deducting the sound pressure level at 500 Hz from 110 decibels. Thus the higher the IIC, the better the impact sound isolation.

IMPACT SOUND INSULATION ($L_{nT,w}$) – Australian Standard AS ISO 717.2 – 2004 has specified that the Impact Sound Insulation of a floor/ceiling system be quantified by operating an ISO 140 Standard Tapping Machine on the floor and measuring the noise generated in the room below. The Weighted Standardised Impact Sound Pressure Level ($L_{nT,w}$) is the sound pressure level at 500 Hz for a reference curve fitted to the measured octave band levels. Thus the lower $L_{nT,w}$ the better the impact sound insulation.

IMPULSE NOISE – An impulse noise is typified by a sudden rise time and a rapid sound decay, such as a hammer blow, rifle shot or balloon burst.

INTRUSIVE NOISE LEVEL, L_{Aeq} – The level of noise from a factory, place of entertainment, etc. in NSW is assessed on the basis of the average maximum noise level, or the $L_{Aeq\ (15\ min)}$. This is the energy average A weighted noise level measured over any 15 minute period.

LOUDNESS – The degree to which a sound is audible to a listener is termed the loudness. The human ear perceives a 10 dBA noise level increase as a doubling of loudness and a 20 dBA noise increase as a quadrupling of the loudness.

MAXIMUM NOISE LEVEL, L_{Amax} – The rms maximum sound pressure level measured on the "A" scale of a sound level meter during a noise survey is the L_{Amax} noise level. It may be measured using either the Fast or Slow response time of the meter. This should be stated.

NOISE RATING NUMBERS – A set of empirically developed equal loudness curves has been adopted as Australian Standard AS1469-1983. These curves allow the loudness of a noise to be described with a single NR number. The Noise Rating number is that curve which touches the highest level on the measured spectrum of the subject noise. For broadband noise such as fans and engines, the NR number often equals the dBA level minus five.

NOISE – Noise is unwanted sound. Sound is wave motion within matter, be it gaseous, liquid or solid. “Noise includes sound and vibration”.

NOISE REDUCTION COEFFICIENT – See: "Sound Absorption Coefficient"

OFFENSIVE NOISE

(Reference: Dictionary of the Protection of the Environment Operations Act 1997).

"Offensive Noise means noise:

(a) *that, by reason of its level, nature, character or quality, or the time at which it is made, or any other circumstances:*

  (i) *is harmful to (or likely to be harmful to) a person who is outside the premise from which it is emitted, or*

  (ii) *interferes unreasonably with (or is likely to interfere unreasonably with) the comfort or repose of a person who is outside the premises from which it is emitted, or*

(b) *that is of a level, nature, character or quality prescribed by the regulations or that is made at a time, or in other circumstances prescribed by the regulations."*

PINK NOISE – Pink noise is a broadband noise with an equal amount of energy in each octave or third octave band width. Because of this, Pink Noise has more energy at the lower frequencies than White Noise and is used widely for Sound Transmission Loss testing.

REVERBERATION TIME, T_{60} – The time in seconds, after a sound signal has ceased, for the sound level inside a room to decay by 60 dB. The first 5 dB decay is often ignored, because of fluctuations that occur while reverberant sound conditions are being established in the room. The decay time for the next 30 dB is measured and the result doubled to determine the T_{60}. The Early Decay Time (EDT) is the slope of the decay curve in the first 10 dB normalised to 60 dB.

SOUND ABSORPTION COEFFICIENT – αSound is absorbed in porous materials by the viscous conversion of sound energy to heat energy as the sound waves pass through it. Sound is similarly absorbed by the flexural bending of internally damped panels. The fraction of incident energy that is absorbed is termed the Sound Absorption Coefficient, α. An absorption coefficient of 0.9 indicates that 90 % of the incident sound energy is absorbed. The average α from 250 to 2000 Hz is termed the Noise Reduction Coefficient (NRC).

SOUND ATTENUATION – If an enclosure is placed around a machine, or a silencer is fitted to a duct, the noise emission is reduced or attenuated. An enclosure that attenuates the noise level by 30 dBA, reduces the sound energy by one thousand times.

SOUND EXPOSURE LEVEL (SEL) – The total sound energy of a single noise event condensed into a one second duration or in other words it is an L_{eq} (1 sec).

SOUND PRESSURE LEVEL, L_p – The level of sound measured on a sound level meter and expressed in decibels, dB, dBA, dBC, etc.. $L_p = 20 \times \log (P/P_o)$ ... dB

where P is the rms sound pressure in Pascal and P_o is a reference sound pressure of 20 µPa. L_p varies with distance from a noise source.

SOUND POWER LEVEL, L_w – The Sound Power Level of a noise source is an absolute that does not vary with distance or with a different acoustic environment.

$L_w = L_p + 10 \log A$ ... dB, re: 1pW,

where A is the measurement noise-emission area in square metres in a free field.

SOUND TRANSMISSION CLASS (STC) – An internationally standardised method of rating the sound transmission loss of partition walls to indicate the decibels of noise reduction of a human voice from one side to the other. (Refer: Australian Standard AS1276 – 1979)

SOUND TRANSMISSION LOSS – The amount in decibels by which a random sound is reduced as it passes through a sound barrier. A method for the measurement of airborne Sound Transmission Loss of a building partition is given in Australian Standard AS1191 - 2002.

STATISTICAL EXCEEDENCE SOUND LEVELS, L_{A90}, L_{A10}, L_{A1}, etc. – Noise which varies in level over a specific period of time (usually 15 minutes) may be quantified in terms of various statistical descriptors:

The L_{A90} is the dBA level exceeded for 90 % of the time. In NSW the L_{A90} is measured over periods of 15 minutes, and is used to describe the average minimum or background noise level.

The L_{A10} is the dBA level that is exceeded for 10 % of the time. In NSW the L_{A10} measured over a period of 10 to 15 minutes. It was until recently used to describe the average maximum noise level, but has largely been replaced by the L_{Aeq} for describing level-varying noise.

The L_{A1} is the dBA level that is exceeded for 1 % of the time. In NSW the L_{A1} may be used for describing short-term noise levels such as could cause sleep arousal during the night.

STEADY NOISE – Noise, which varies in level by 6 dBA or less, over the period of interest with the time-weighting set to “Fast”, is considered to be “steady”. (Refer AS 1055.1 1997)

WEIGHTED SOUND REDUCTION INDEX, R_w – This is a single number rating of the airborne sound insulation of a wall, partition or ceiling. The sound reduction is normally measured over a frequency range of 100 to 3,150 Hertz and averaged in accordance with ISO standard weighting curves (Refer AS/NZS 1276.1:1999).

Internal partition wall R_w + C ratings are frequency weighted to simulate insulation from human voice noise. The R_w + C is always similar in value to the STC rating value. External walls, doors and windows may be $R_w + C_{tr}$ rated to simulate insulation from road traffic noise. This is normally a lower number than the STC rating value.

WHITE NOISE – White noise is broadband random noise whose spectral density is constant across its entire frequency range. The sound power is the same for equal bandwidths from low to high frequencies. Because the higher frequency octave bands cover a wider spectrum, white noise has more energy at the higher frequencies and sounds like a hiss.

Table 4.1 Modifying factor corrections
(See definitions in Section 4.2)

Factor	Assessment/ Measurement	When to apply	Correction[1]	Comments
Tonal noise	One-third octave or narrow band analysis	Level of one-third octave band exceeds the level of the adjacent bands on both sides by: - **5 dB** or more if the centre frequency of the band containing the tone is above 400 Hz - **8 dB** or more if the centre frequency of the band containing the tone is 160 to 400 Hz inclusive - **15 dB** or more if the centre frequency of the band containing the tone is below 160 Hz	5 dB[2]	Narrow-band frequency analysis may be required to precisely detect occurrence
Low frequency noise	Measurement of C-weighted and A-weighted level	Measure/assess C- and A-weighted levels over same time period. Correction to be applied if the difference between the two levels is 15 dB or more	5 dB[2]	C-weighting is designed to be more responsive to low-frequency noise
Impulsive noise	A-weighted fast response and impulse response	If difference in A-weighted maximum noise levels between fast response and impulse response is greater than 2 dB	Apply difference in measured levels as the correction, up to a maximum of 5 dB.	Characterised by a short rise time of 35 milliseconds (ms) and decay time of 1.5s
Intermittent noise	Subjectively assessed	Level varies by more than 5 dB	5 dB	Adjustment to be applied for **night-time only.**
Duration	Single-event noise duration may range from 1.5 min to 2.5 h	One event in any 24-hour period	0 to –20 dB(A)	The acceptable noise level may be increased by an adjustment depending on duration of noise. *(See Table 4.2)*
Maximum Adjustment	Refer to individual modifying factors	Where two or more modifying factors are indicated	Maximum correction of 10 dB(A)[2] (excluding duration correction)	

Notes:
1. *Corrections to be added to the measured or predicted levels.*
2. *Where a source emits tonal and low-frequency noise, only one 5-dB correction should be applied if the tone is in the low-frequency range.*