Berrimah Zone Substation Condition Assessment Report

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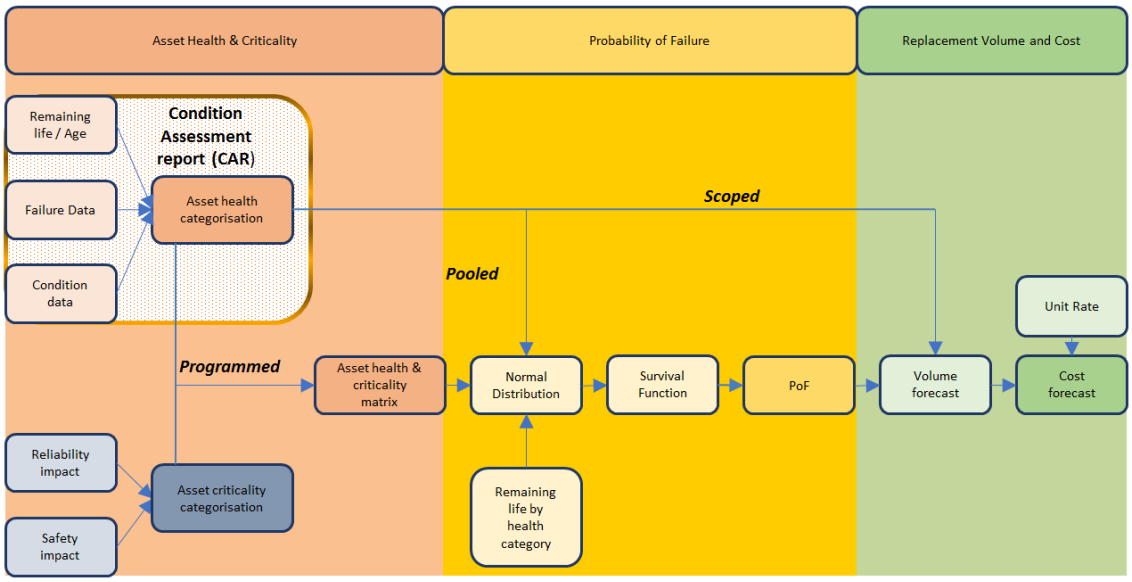
1 Introduction

This condition assessment report (CAR) provides a structured condition assessment of all the assets in a format aligned to the PWC asset hierarchy[1] and applying the condition assessment criteria[2] for each asset class within the Berrimah ZSS. The CAR collates and summarises information from various PWC data sources that are either in raw data format or conditioned data and is traceable to the source. The following diagram illustrates where the CAR sits within the asset management process within PWC.

[1] Refer to PWC document D2015/354287 Asset Data Template
[2] Refer to PWC document D2018/65161 for a complete description of the PWC condition assessment methodology.

Figure 1 - Role of CAR in the PWC asset management process



The output of the CAR is an assessment of remaining serviceable life before some form of intervention is required for the asset to continue to provide the service it was designed for. The information within the CAR is used as an input to determine the most effective asset class managent plan and by definition the CAR **does not include a criticality assessment**.

2 Summary

The following table and commentary provides a summary of the asset health at Berrimah ZSS. Table 1 describes the asset health definitions used in this CAR. A more detailed breakdown of the asset health components and scores can be found in section 5.

Table 1 - Asset health definitions

Code	Definition[3]	Asset Health Rating range
	Loss of required function within 5 years	*2.34 - 3*
	Loss of required function within 5-15 years	*1.68 – 2.33*
	New asset / minor degradation (remaining life beyond 15 years)	*1 – 1.67*

[3] Consistent with PWC Assets Health and Criticality Methodology document D2018/72550

Table 2 - Summary of asset health

Asset Class	Sub Asset	Asset Health Rating
Building structures	*Overall*	*1.8*
Civils / earthgrid	*Overall*	*1*
Protection	*Overall*	*1.92*
HV cable	*Overall*	*1.75*
ZSS TF's	*Overall*	*N/A*
	TF1	*2*
	TF2	*2.7*
11/22kV indoor switchboard	*Overall*	*1.53*
	Bus 1 - Hawker / Siddley vacuum re-fit	*1.3*
	Bus 2 - Hawker / Siddley vacuum re-fit	*1.3*
	Bus 3 – Reyrolle vacuum	*2*
66kV CB's	*Overall*	*N/A*
	CB 66BE201	*2.35*
	CB 66BE202	*2.6*
	CB 66BE203	*2.5*
	CB 66BE204	*1.25*
	CB 66BE502	*2.5*
	CB 66BE503	*2.35*
SCADA	*Overall*	*2*
Comms	*Overall*	*2*
Capacitor banks	*Overall*	*2*
Airconditioning	*Overall*	*2.5*
	Airconditioning	*3*
	Dehumidifier	*2*
66kV Isolators	*Overall*	*2*
66kV inst TF's	*Overall*	*1.91*
Fire systems	*Overall*	*3*
Aux TF	*Overall*	*2*
LV board	*Overall*	*3*
DC supplies	*Overall*	*3*
66kV busbar	*Overall*	*2*

The following additional commentary is provided to complement the above summary in relation to significant asset classes by exception.

Protection

The majority of the protection relays are over 15 years old with a significant number over 25 years old and are no longer supported. There have been upgrades to one transmission line protection due to the construction of new zone substations to match line protection on the

remote end. At the last routine maintenance in 2016, 7 out of the 81 relays were found to be out of setting tolerance during routine maintenance.

ZSS Transformers

The current DP values have been calculated by using the paper sample DP value on Tx2 (246) and lowest DP value for Tx1 from furan analysis (522) and extrapolating to the current date using Power and Waters' average yearly fleet rate of decline[4]

TF1

The DP calculated from Furan results is 510 rather than a direct measurement of paper samples. Given this TF is the same type, year, duty as TF2 it is possible that the DP is overstated.

TF2

Paper samples were taken on Berrimah Tx2 in a number of locations by Alstom in 2013 during a transformer overhaul. The samples revealed an estimated DP of 246 and using the rate of decline curve puts the DP currently at 186.

During the overhaul in 2013, sludge and metal debris was found throughout the transformer. The sludge was likely due to oil regeneration which occurred in 1998, since very poor oil quality was recorded in subsequent years. It is expected that the metal debris was generated by the failing oil pump and distributed around the transformer prior to the pump failing. Attempts were made to remove the sludge and metal debris in June 2013 by flushing with clean oil (in situ, core and windings were not removed). Limited success was achieved due to the sludge hardening over time. The presence of thick hardened sludge within the main tank of the transformer will affect heat dissipation from the windings under load and its rating is under review.

11/22kV Switchboard

The 11kV switchboard at Berrimah was installed as part of the original substation establishment. In 1997 the switchboard was extended with three panels of Reyrolle vacuum CBs, and in 2009 the original Brush oil CBs were replaced by Hawker Siddeley vacuum retro-fit CBs. All 11kV circuit breakers are in good condition and no major condition related issues have been experienced. It is expected that their full service life can be achieved. The main concern with this switchboard is that it is does not have appropriate arc-fault containment and there is inadequate protection to quickly isolate the bus in the event of a bus fault. There was a flashover incident in 2017 on this switchboard resulting in second degree burns to the switching operator.
Frame Earth Leakage is used on similar switchboards in PWC to provide this protection, however this has been disabled at Berrimah due to the degradation of panel insulation and subsequent spurious bus trips that resulted in widespread outages.

66kV Circuit Breakers

Five of the six CBs at Berrimah are ASEA HLC models which are installed widely across the PWC network. Several of this type of CB have experienced failures with the most recent catastrophic failure in 2011 at Hudson Creek Zone Substation[5]. They are becoming increasingly unreliable as the fleet ages. One of the primary causes of failure is contamination of the oil interrupting medium with water. The HLC circuit breaker is a "free-breathing" design. In the humid and wet

[4] Refer Asset Management Plan – Power Transformers D2017/242382
[5] Refer Asse Management Plan – High Voltage Circuit Breakers D2017/242384

environment of the Darwin region, significant amounts of moisture can enter the breaker and build up over time. This is exacerbated by oil leaks, which are becoming more frequent as a result of ageing seals and sealing surfaces perishing or being damaged over time. As a result significant volumes of "free" water (i.e. water below the oil) must be drained from the circuit breaker stacks at each maintenance outage. The presence of free water considerably increases the risk of the circuit breaker failing to break fault currents when required, since it lowers the dielectric. Insulation resistance testing is performed during routine maintenance to ensure the integrity of the circuit breaker insulation, and is a useful indicator for the presence of moisture and degraded oil. The failure rate for "as-found" insulation resistance is approximately 30% since testing began in 2008. By comparison, the failure rate for non-HLC circuit breakers is approximately 7%..

There also have been multiple instances of mechanisms seizing, operating slowly, or tripping through (tripping immediately after closing). The failure rate for "as-found" opening time during routine maintenance is approximately 15%. Mechanism failures can usually be restored by maintenance crews, however there have been instances where restored mechanisms have failed again shortly afterwards, requiring multiple outages and visits to correct. The mechanism failures are thought to be caused by the build-up of dirt and corrosion, failed dampers and inadequate lubrication over long periods. To resolve these issues a complete refurbishment of the mechanisms is required.

PWC experience indicates that end of life for these CBs in the PWC network is around 40 years. Routine maintenance activities over the life of these circuit breakers have not been effective at maintaining their condition. Contemporary asset management practices have been applied to these assets since the 2008 Davies Review into a major substation failure within PWC. However the failure modes targeted through maintenance are consistently recurring indicating major refurbishment or replacement is necessary.

There is only one non HLC type CB at Berrimah. CB 66BE204 is an ABB EDF model which was installed to replace a failed HLC unit in 2007. This model of CB has also experienced reliability issues with contact resistance results increasing above specification values on several of these units in the PWC network. ABB has recommended an intrusive maintenance on this unit as soon as possible

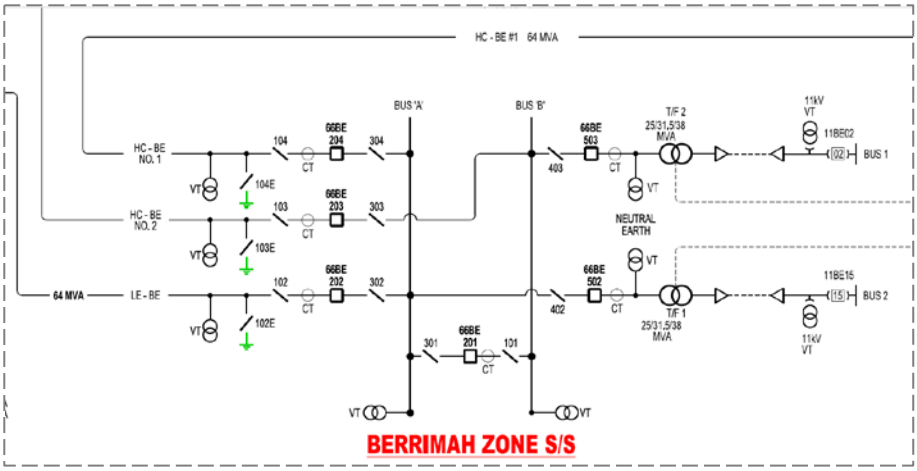
Instrument Transformers

The 66kV instrument transformers are mostly the original units (or units of the same vintage which have been used as spares) manufactured in the late 1970s. The instrument transformers have experienced several condition-related problems in recent years:

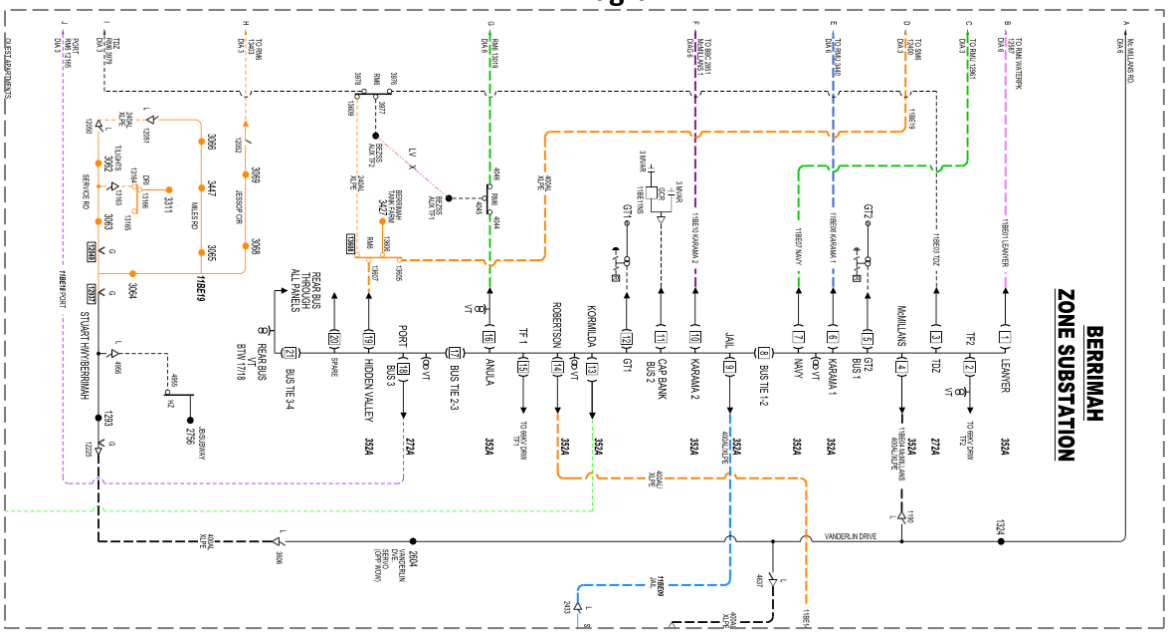
- Two VTs currently have low insulation resistance,
- Two VTs and a CT currently have poor dissolved gas analysis results,
- Two VTs have high levels of partial discharge activity,
- One set of VTs is unable to be tested, as they have internal earth connections which can not be removed,
- Two current transformers have failed testing and been replaced at Berrimah since 2010.

3 Single Line Diagram

66kV Diagram



11kV Diagram



4 Site Overview

Berrimah Zone Substation was established in 1981. The substation is supplied by three overhead 66kV lines and the 66kV bus is configured as two straight buses with a bus coupler. The 66kV yard is an outdoor type and the CB's are mostly minimum oil type. There are two 66/11 kV 25MVA transformers supplying an indoor 11kV switchboard that has three sections. The 11kV switchboard at Berrimah was installed as part of the original substation establishment. In 1997 the switchboard was extended with three panels of Reyrolle vacuum CBs, and in 2009 the original Brush oil CBs were replaced by Hawker Siddeley vacuum retro-fit CBs.

There are also two decommissioned gas turbines and associated connection transformers on the site.

5 Asset Condition Assessment

The following asset condition assessment is based on the current PWC condition assessment criteria for its various asset classes. The supporting test results and values where applicable have been extracted from relevant PWC asset databases and reports.

The three levels of asset health are characterised as follows.

Code	Definition[6]	Asset Health Rating range
	Loss of required function within 5 years	*2.34 - 3*
	Loss of required function within 5-15 years	*1.68 – 2.33*
	New asset / minor degradation (remaining life beyond 15 years)	*1 – 1.67*

Asset Class	Sub Asset	Remaining serviceable life criteria	Asset Health Rating	Comments / Source
Building structures		***Overall***	***1.8***	
		Independent structural report / site inspection report	**1**	No significant issues.
		Asbestos rating	**2**	The building contains asbestos but is managed.
		Age	**2**	This is the original building established in 1981 so will be 40 years old in the RY2020-24 regulatory period.
Civils / earthgrid		***Overall***	***1***	
		Earthgrid test results	**1**	Minor remedial work estimated at about $20k. D2017/204690 Substation Earthing Recommendation and Cost Estimation. D2016/330243 FortEng Earthing Report.

[6] Consistent with Assets Health and Criticality Method D2018/72550

Asset Class	Sub Asset	Remaining serviceable life criteria	Asset Health Rating	Comments / Source
		Assessment of switchyard	**1**	No significant issues.
Protection		***Overall***	***1.92***	
		Technology type	**1.9**	16 electromechanical 40 static 25 digital
		Relay calibration	**2**	D2018/60081 Relay Defect Report
		Failure rate		Future measure
HV cable		***Overall***	***1.75***	
		Construction technology / design / installation	**1.75**	D2018/71336
ZSS TF's		***Overall***	***N/A***	
	TF1	Overall	**2**	
		Degree of polymerisation	**2**	Ref: D2017/564540 Berrimah Transformer CAR
		Oil Analysis	**2**	Output from 'TxAnalyser' platform
		Age	**2**	
	TF2	Overall	**2.7**	
		Degree of polymerisation	**3**	Ref: D2017/564540 Berrimah Transformer CAR
		Oil Analysis	**2**	Output from 'TxAnalyser' platform
		Age	**2**	
11/22kV indoor switchboard		***Overall***	***1.53***	D2017/382530 BEZSS Operator Report D2017/430661 BEZSS ICAM investigation report
	Bus 1 - Hawker / Siddley vacuum re-fit	Overall	**1.3**	
		Age	**1**	Original 1980 CB's with vacuum interrupter re-fit in 2009
		Functional / Safety / operational issues	**2**	

Asset Class	Sub Asset	Remaining serviceable life criteria	Asset Health Rating	Comments / Source
		Partial Discharge		Future measure
	Bus 2 - Hawker / Siddley vacuum re-fit	Overall	**1.3**	
		Age	**1**	Original 1980 CB's with vacuum interrupter re-fit in 2009
		Functional / Safety / operational issues	**2**	
		Partial Discharge		Future measure
	Bus 3 – Reyrolle vacuum	Overall	**2**	
		Age	**2**	Installed in 1979
		Functional / Safety / operational issues	**2**	
		Partial Discharge		Future measure
66kV CB's		***Overall***	***N/A***	For all the following asset health parameters and calculation - parameters D2018/13333 HV Circuit Breakers Test Results Health and Criticality – all breakers
	CB 66BE201	Overall	**2.35**	
		Age	**2**	
		Condition Assessment	**3**	
		Defect count	**2**	
		Defect cost	**1**	
		Insulation technology	**2**	
		Mechanism technology	**1**	
	CB 66BE202	Overall	**2.6**	

Asset Class	Sub Asset	Remaining serviceable life criteria	Asset Health Rating	Comments / Source
		Age	2	
		Condition Assessment	3	
		Defect count	3	
		Defect cost	3	
		Insulation technology	2	
		Mechanism technology	1	
	CB 66BE203	Overall	2.55	
		Age	2	
		Condition Assessment	3	
		Defect count	2	
		Defect cost	1	
		Insulation technology	2	
		Mechanism technology	1	
	CB 66BE204	Overall	1.15	
		Age	1	
		Condition Assessment	1	
		Defect count	2	
		Defect cost	2	
		Insulation technology	1	
		Mechanism technology	1	
	CB 66BE502	Overall	2.55	
		Age	2	
		Condition Assessment	3	
		Defect count	2	
		Defect cost	3	
		Insulation technology	2	
		Mechanism technology	1	
	CB 66BE503	Overall	2.35	

Asset Class	Sub Asset	Remaining serviceable life criteria	Asset Health Rating	Comments / Source
		Age	2	
		Condition Assessment	3	
		Defect count	2	
		Defect cost	1	
		Insulation technology	2	
		Mechanism technology	1	
SCADA		***Overall***	***2***	
		Age	2	D2017/319807
		Failure rate		Future measure
Comms		***Overall***	***2***	
		Age	2	D2017/319807
		Failure rate		Future measure
Capacitor banks		***Overall***	***2***	
		Age	2	Original units since 1981. D2017/230246
Airconditioning		***Overall***	***2.5***	
	Airconditioning	Age	3	D2018/74141
	Dehumidifier	Age	2	
66kV Isolators		***Overall***	***2***	
		Age	2	D2017/230246 Age profile data
66kV inst TF's		***Overall***	***1.91***	
		Age	2	D2017/230246 Age profile data
		Condition Assessment	1.7	Output from TxAnalyser
Fire systems		***Overall***	***3***	
		Defect cost		Future measure
		Age/Functionality/obsolescence	3	BEZSS BC D2017/326652 & ZSS BNI D2018/62078
Aux TF		***Overall***	***2***	
		Age	2	Original units since 1981.
LV board		***Overall***	***3***	

Asset Class	Sub Asset	Remaining serviceable life criteria	Asset Health Rating	Comments / Source
		Age	**3**	Original unit. Ongoing issues with CFS breakers & faulty change-over D2018/76070
DC supplies		***Overall***	***3***	
		Age	**3**	D2017/230246 Age profile data
66kV busbar		***Overall***	***2***	
		Age	**2**	Original units since 1981. D2017/230246