Wanniassa Zone Substation Earth Grid Conditioning Report

PSD078319c002

Prepared for

ActewAGL

16 Williams Circuit
Pooraka SA 5095
Telephone: +61 (0)8 8259 8100
Fax: +61 (0)8 8259 8101

Report Status

Name of Report	Wanniassa Zone Substation Earth Grid Conditioning Report
Document Number	PSD078319c002
Prepared By	T Strydom
Prepared For	ActewAGL
Report Revision	2
File Name	PSD078319j002_r02 - Wanniassa Earthing Test Report.doc

Report History

Rev	Revision Description	Date Issued	Reviewed By	Approved By
1	Draft issue	19/01/2015	E Jayagan	T Strydom
2	Included ActewAGL comments	6/02/2015	E Jayagan	T Strydom

Executive Summary

This report details the result of the earthing test conducted by PSD Energy at Wanniassa Zone Substation. The objective was to measure the earth resistance of the earthing installation and to verify if there are unsafe step and touch voltages in the substation and surroundings.

Visual Inspection: 👎 The visual inspection was done during the testing of the substation, generally the installed earthing are in accordance with the drawings.

It is observed that the fences have been upgraded. This however is not reflected on all drawings. There is a separate fence earthing drawing. It is proposed that this information should be reflected on all the substation drawings.

👍 The fence is earthed in accordance with the industry standards at every second fence post via a 40x3mm copper flat strap as per the drawings. The primary plant is earthed in accordance with the drawings via a 40x3mm copper flat strap. The earth grid was exposed by hand digging and this verified the main grid and connections are in good order and conductor sizes as per drawing. The site yard stone is in good condition and well within the required 100mm layer thickness.

Grid Resistance Measurement: The Fall-of-Potential Test was carried out to determine the combined earth resistance of the Wanniassa ZS earthing system, which consists of local substation earth grid and remote earthing connected to the substation via the overhead earth wire. The test current probe or remote earth was installed approximately 650 metres north from the northeast corner of the substation. The voltage test probes were run east, starting at a distance of 500m from the northeast corner of the substation.

👍 The measured combined earth resistance of the earth system was 0.2Ω. The 132kV fault level was considered the worst fault level for internal substation faults. And after considering the percentage of fault current that being diverted onto the remote earth via the overhead ground wire, the earth resistance of the local earth grid is calculated to be 0.40 Ω. This value is less than the resistance of the earth grid modelled in CDEGS which is 0.57321 Ω.

At unlikely event of a substation earth fault with a magnitude of 16.71 kA, the grid will produce an Earth Potential Rise (EPR) of 3.3kV

Step and Touch Potentials: A six (6.19) ampere current was injected into the substation earth grid to simulate a fault scenario. The voltage measurements were taken in order to confirm that the step and touch voltages within the substation were within the required safe voltage limits.

Step potentials were measured on the outside perimeter of the substation and the inside of the substation. The step voltage measurements verified that there is no dangerous step voltage inside and outside the substation.

Touch potentials were measured on the outside perimeter of the substation and the inside of the substation. Touch potentials are generally within the safety limits except in the north western corner of the fence. This requires remedial action.

Equipment Bonding: PSD performed equipment bonding measurements on the primary infrastructure in the substation. This was done using 4wire resistance measurements. All measurements are done to one common point. The purpose of this test is to verify that the plant is bonded to the grid and that the bonding resistance is of low impedance.

There are a number of structures in the substation that have bonding resistance readings above the required limit of 10mΩ. Some of the structures within the substation are painted and some of the connections seem to be onto the painted surface only. There are also a number of operators earth mats that have poor connections back to the earth grid. This will require remedial action. It is proposed that the connections to the structure are disconnected, cleaned and reconnected.

Table of Contents

Table of Figures

Table of Tables

1. Introduction

This report details the result of the testing conducted by PSD Energy on the existing earth grid of Wanniassa Zone Substation.

The objective was to measure the resistance to earth of the installed earthing installations and the step and touch potentials that will be produced at unlikely event of electrical faults.

The earthing tests consisted of:

1. Fall-of-Potential Test to measure the earth resistance of the existing earthing installation;
2. Step and touch voltage measurements;
3. Four Pin Wenner Method to measure the soil resistivity at Wanniassa ZS and surroundings; and
4. Continuity Test to verify the loop resistance between the earthing tails or risers connected to each support structures and equipment, and the main earth grid.

A six (6.19) ampere current was injected into the substation earth grid to simulate a fault scenario. A frequency voltmeter was used to measure the step and touch voltages on the access doors, transformer enclosure, steel support structures, stairs, and perimeter fence.

Figure 1 - Wanniassa Zone Substation

WANNIASSA ZONE SUBSTATION
In parkland on Cnr of Sulwood Drive & Athlon Drive,
Wanniassa ACT
Google Coordinates:-35.384046, 149.09547

2. Glossary

Clearing Time:	Time taken for the protective devices and circuit breaker to isolate the fault current.
Coupling Factor:	It is the magnitude of the current returned on a faulted cable's screens and sheath expressed as a percentage of the fault current magnitude.
Earth Grid:	It is a connection usually made by burying metallic conductors in the soil, to the greater mass of the earth.
Earth Potential Rise (EPR):	The maximum voltage that a station earth grid will attain relative to a distant earthing point assumed to be at the potential of remote earth.
Fault Current:	The current flowing as the result of a line to ground fault on the power system.
Induced Voltage:	It is the voltage on a metallic structure resulting from the electromagnetic or electrostatic effect of a nearby power line.
Mesh Voltage:	The mesh is the touch voltage within a mesh, and the maximum value is used for design purposes.
Mutual Earth Resistance (MER):	MER is an occurrence whereby voltage coupling between earth systems affects the apparent impedance of the combined systems. Soil resistivity structure, system sizes and separation, and current relationship contribute to MER's significance.
Prospective Step Voltage:	The open-circuit voltage difference between two points on the earth's surface separated by a distance equal to a man's normal step (approximately 1 meter).
Prospective Touch Voltage:	The open circuit voltage difference between an earthed metallic structure (within 2.4 meters of the ground), and a point on the earth's surface separated by a distance equal to a man's normal horizontal reach (approximately 1 meter).
Proximity Effect:	Phenomenon whereby diminishing returns are obtained by installing more and more in-ground earthing in proximity to an existing system. Soil resistivity structure, system sizes and proximity, and current relationship contribute to the significance of proximity effect.

Shielding Factor:	One hundred per cent minus the magnitude of the current not returned on a faulted cable's screens and sheath expressed as a percentage of the fault current magnitude.
Step Voltage:	The difference in surface potential experienced by a person's body bridging a distance of one meter with his feet without contacting any other grounded object.
Touch Voltage:	The voltage across a body, under fault conditions, in a position described as for the Prospective Touch Voltage but allowing for the voltage drop caused by a current in the body.
Transfer Voltage:	A special case of Prospective Touch Voltage where the metallic structure is connected to a remote point or alternatively is connected to the station grid and is touched at a remote location.

3. Standard, References and Specifications

3.1. Australian Standards

[1] AS2067:2008: Substations and high voltage installations exceeding 1kV a.c.

[2] AS/NZS 4853:2012: Electrical Hazards on Metallic Pipelines

[3] AS/NZS 3835.1:2006: Earth Potential Rise – Protection of Telecommunications Network Users, Personnel and Plant. Part 1: Code Of Practice

[4] AS/NZS 3835.2:2006: Earth Potential Rise – Protection of Telecommunications Network Users, Personnel and Plant. Part 2: Application Guide

[5] AS/NZS 3000:2007: Wiring Rules

[6] AS/NZS 3007.2:2004'Electrical installations - Surface mines and associated processing plant - Part 2: General protection requirements'

[7] AS/NZS 1768:2007: Lightning Protection

[8] AS/NZS 7000:2010:Overhead Line Design – Detailed Procedures

3.2. Earthing Guidelines

[9] ENA EG0:2010: Power System Earthing Guide

[10] ENA EG1:2006: Substation Earthing Guide

3.3. IEEE Standards

[11] IEEE Standard 80 (2000): Guide for Safety in AC Substation Grounding

3.4. ActewAGL's Standard and References

[12] Drawing 2205-0000 Wanniassa Zone Substation Single Line Diagram

[13] Drawing 2205-6202 Wanniassa Zone Substation Extension Earthing Arrangement

[14] Drawing 2205-6002 Wanniassa Zone Substation Extension General Arrangement

4. Abbreviations

AC	Alternating Current
DC	Direct Current
HV	High Voltage
LV	Low Voltage
MEN	Multiple Earth Neutral
PVC	Polyethylene Vinyl Chloride
RESAP	Soil Modelling Module of CDEGS
MALZ	Earth mat design module of CDEGS package
HIFREQ	High Frequency Earth mat design module of CDEGS package
CDEGS	Earthing Simulation Software
ZS	Zone Substation

5. Scope

The scope of work for the Wanniassa ZS consists of measuring the earth resistance of the earthing installation and to verify if there are unsafe step and touch voltages in the substation and surroundings.

5.1. Specific Requirements

The earth grid is to be measured, tested and assessed against the standards listed in Section 3.

The earth grid safety performance is based on maximum calculated prospective fault level as per Section 6 - Network configuration and parameters.

- the earthing system is based on the requirements and recommendations of AS2067, IEEE Standard 80 and ENA EG1 -2006 Substation Earthing Guide
- personnel safety by limitation of touch and step potentials to safe values during fault conditions;
- to limit the maximum rise in earth potential (EPR) relative to a remote earth during fault conditions to a value not exceeding the safe touch potential;
- to ensure that the exposed metalwork of electrical equipment cannot reach hazardous potential due to insulation failure

5.2. Earthing Tests Required

The following earth tests to be performed:

1. Substation Grid resistance measurements;
2. Substation Grid EPR measurements;
3. Step and touch potentials measurements;
4. Structure and operator earth bonding resistance.

6. Network configuration and parameters

It is important to understand the network configuration and network earthing practices in order to accurately analyse the fault current distribution in a substation.

The earthing configuration is determined by the electrical system requirements such as overhead line connections, transformers and primary pant earthing philosophy (solid, inductive or resistive earthing). It also depends on the geographical location of the substation.

The safety and mechanical performances of the earthing system depend on the overall earthing configuration and earth grid impedance.

The impedance of an earthing system is dependent on the earth grid installed, soil resistivity and the area or footprint of the substation. It is influenced by the presence of auxiliary or secondary earthing systems, which lower the overall impedance by providing additional paths for the conduction of fault current. The auxiliary earthing systems include all metalwork bonded into the primary earthing system; typical examples are OHEWs, cable sheaths and pipelines.

6.1. Fault Levels and Clearing Time

The fault levels and protection clearing time are tabulated in Table 1.

Table 1 – Fault Levels and Clearing Time for Safety Performance

Fault Source	Fault	Maximum Earth Fault Level (kA)	Foreseeable Future Earth Fault Level (kA)	Primary Clearing Time (s)
Wanniassa 132 kV	phase to ground	16.71	20.05	0.5
Wanniassa 11 kV	phase to ground	3.97	4.76	0.5

Notes:

1. "Foreseeable Future" refers 10 to 15 years development plan for Wanniassa ZS, no values has been provided for foreseeable future. We allowed a factor of 1.20 for future expansion.
2. The earth fault clearance time of protection relays is an assumption and based on the guidelines in the IEEE Std 80 and industry practice. No values were provided by the ActewAGL.

The Wanniassa ZS 132kV transmission consists of overhead lines, which are fitted with overhead earth wire. The overhead earth wire is connected back to the substation. The 132kV system is solidly earthed at the transformer. Any internal earth fault current will flow back directly to the transformer neutral via the earth conductor simulating a short circuit scenario. The EPR is significantly low or close to nil.

In case of 132kV earth fault external to the substation, the fault will be split between the network earthing system and the substation earth grid. The return fault current is likely to be lower than the maximum internal fault current. This current will produce an EPR.

The 11kV system is inductively earthed via a z-connected earthing transformer. Any internal fault current will flow back directly to the transformer neutral via the earth conductor and will therefore not produce an EPR. The z-connected earthing transformer will also limit the fault current within predetermined design values.

The 11kV distribution consists of cables and overhead line network. The cables are single point bonded and the overhead lines have no overhead earth wire. 11kV faults external to the substation is likely to be the highest for an external fault. The fault current will return to substation earth grid via earth cable and/or natural earth (ground), and therefore will produce an EPR.

As the 132 kV earth fault level is higher than 11 kV, The Wanniassa 132 kV Foreseeable Future Earth Fault Level (kA) will be used as the worst case fault level for the purpose of this report.

6.2. Current Splits

Current distribution measurements were taken with a flexible Rogowski coil to understand the earthing contribution from the various auxiliary paths. Please see Appendix B for site measurements. Table 2 - Current Distribution shows the percentage of current measured in the various auxiliary paths.

Table 2 - Current Distribution

	Max Fault Current (kA)	Calculated Ig Ground Current (kA)	% Split
Earth Grid	16.71	8.31	49.76
132kV OHEW	16.71	8.40	50.24

Table 3 - Future Current Distribution

	Max Fault Current (kA)	Calculated Ig Ground Current (kA)	% Split
Earth Grid	20.05	9.98	49.76
132kV OHEW	20.052	10.07	50.24

The current split testing provides a conservative approximation of the 132 kV OHEW performance as well as other impedances. From the test results, an estimate of the existing grid resistance of Wanniassa ZS can be made by the division of measured EPR and the current dissipated by the earth grid only. The Present Day ground current is **8.31kA** and the Future ground current is **9.98kA.** These values are the worst case grid fault current that will be used for the safety assessment in this report.

7. CDEGS Earth grid model

7.1. General

The CDEGS software suite was used to develop the earth system design.

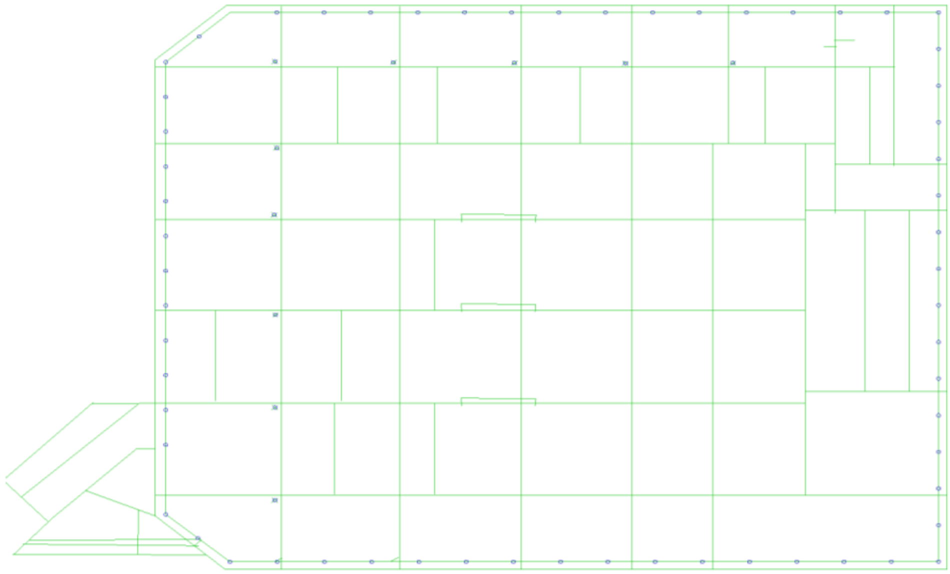
The RESAP module was used to generate the multi-layer soil model using soil resistivity test data collected at site.

The MALZ module was used to model the grid resistance of the substation, EPR, step, touch and transfer potentials resulting from a fault current flowing through the earth.

7.2. Grid Model

The existing earth grid of Wanniassa ZS, as shown in drawing 2205-6202, was updated to reflect the site condition when the earthing test was carried out. The model, which was used to analyse the earthing test results in CDEGS software package, is shown in Figure 2.

Figure 2 - Substation Grid Model



7.3. Modelled System Components

The Earth Grid:

The earth grid consists of a combination of 19/0.101 HBCC and 40x3 mm copper buried at a nominal depth of 750 mm to 1000mm below ground and laid in a mesh configuration. Drawing 2205-6202 shows the arrangement of the earth conductors installed at Wanniassa ZS.

Earth Rods:

Earth rods were model in accordance with drawing 2205-6202, 10 off, 3 metre long copper in drilled holes and backfilled with bentonite.

Concrete Structures:

Concrete structure was not modelled as part of the assessment. This will introduce a margined of error in the earthing model. It would be expected that the actual grid resistance will be reduces due concrete structures in the substation. There error introduce will be on the safe side.

CDEGS advise the following:

"The concrete in a reinforced concrete foundation placed into the ground will assume roughly the same resistivity as that of the surrounding soil, since the resistivity and permittivity of both media is mainly influenced by their moisture content. Furthermore, the resistance of the embedded re-bar foundation will not be affected greatly by the presence of the concrete, as long as the concrete covers approximately the same area as the re-bar. The touch and step voltages above the reinforced concrete foundation are normally not a concern, since the foundation forms (almost) an equipotential plane."

Fencing:

Fencing is represented by modelling the fence as short earth rods. It has been set to energise during fault condition as the fence is directly connected to the earth grid. The fence is one meter inside the substation earth grid.

☝ It is possible to open the substation access gates to the outside of the substation fence.

The substation fence is earthed at the inside of the substation earth grid. There was however a grading ring is installed as part of the fencing upgrade, covering the full swing of the gate.

7.4. Soil Resistivity Model

A soil resistivity tests were carried out by PSD just outside of Wanniassa using the Wenner method, site measurements as detailed in Appendix A. From the test results, the following soil structure was determined using CDEGS software:

Figure 3 - Wenner Test

Figure 4 - Traverse A: E-W

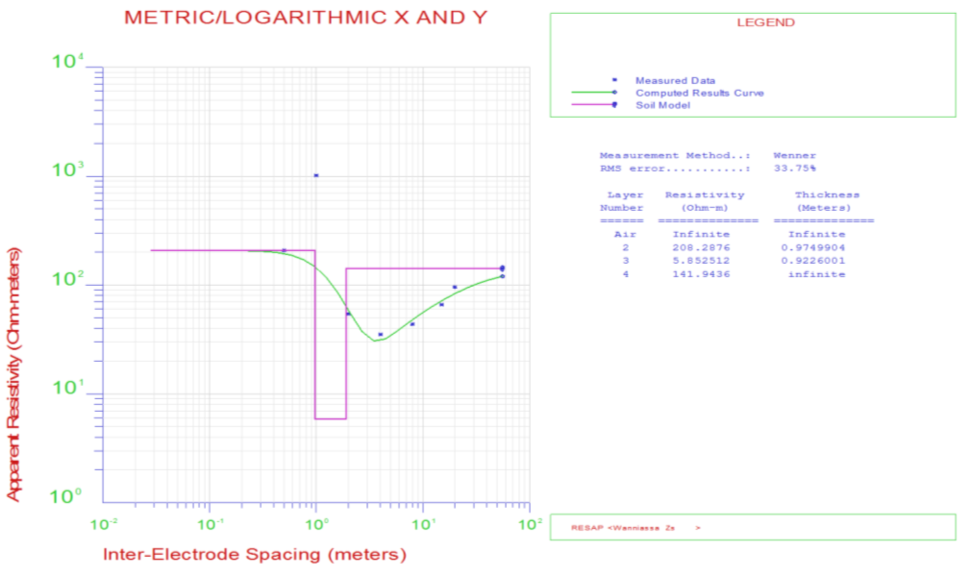


Figure 5 - Traverse B: N-S

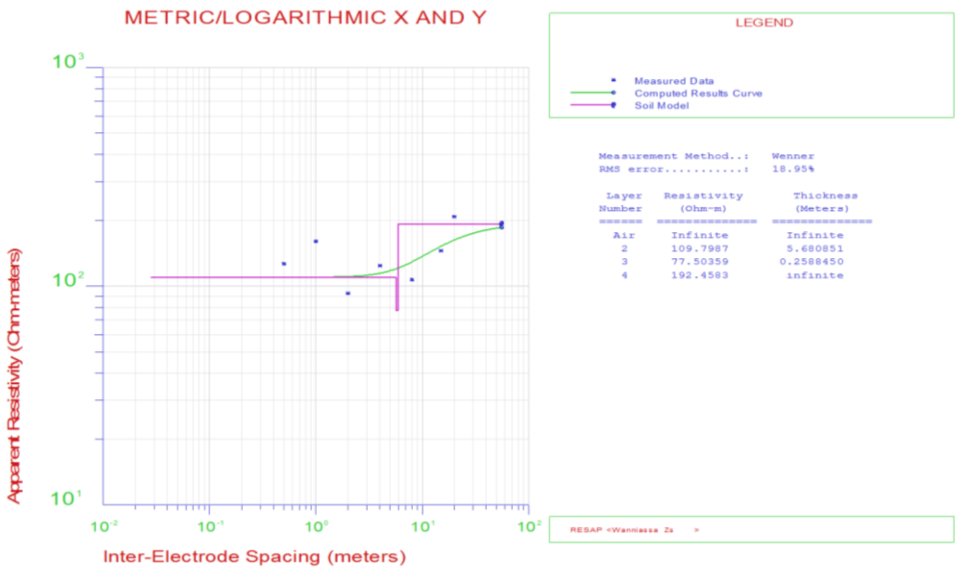


Table 4 - Wanniassa Average Soil Resistivity

Layer	Resistivity	Thickness
1	infinite	infinite
2	208.2876	0.97499
3	5.852512	0.9226
4	141.9436	infinite

The soil properties in Table 4 will be used in the grid assessment and safety calculations.

7.5. Step and Touch Voltages Limits as per IEEE 80:2000

The 50 kg limits apply to public areas, while 70 kg for restricted areas. Hand to hand limits apply to areas where objects of different potential can be bridged by two hands, such as gates, or supporting structures. A resistance of 1000 ohms for footwear is used in the calculation of permissible step and touch voltage limits, in accordance with ENA EG1 and IEEE 80.

Generally, the ground surface of Wanniassa ZS is covered with a high resistance aggregates and concrete pad. The soil resistivity test results suggest the upper soil layer in the substation is 208Ω-m.

Section 4.4.3 Safety Criteria Applicable of ENA EG1 provides a guideline on how to calculate the allowable maximum step and touch voltages for a human body with a fault clearing time of 0.5 second. The results are tabulated in Table 5 – Maximum Permissible Step & Touch Voltages .

Table 5 – Maximum Permissible Step & Touch Voltages

Insulating Layer	50 kg Step Voltage (V)	50 kg Touch Voltage (V)	70 kg Step Voltage (V)	70 kg Touch Voltage (V)
Natural Soil Resistivity (Top Layer) = 170 *Ω.m*	369.06	215.30	499.51	291.40
Aggregates = 3000 Ω.m	2115.34	651.87	2863.00	882.27
Concrete/Asphalt = 10000 Ω.m	3852.65	1086.20	5214.36*	1470.11
Hand to Hand Touch Limit	164.05		222.03	

7.6. Calculated Earth Resistance of Existing Earth Grid in CDEGS

Using the soil resistivity test result in Section 7.4 and the earth grid model shown in Figure 2 - Substation Grid Model, the calculated earth resistance of Wanniassa ZS earthing in CDEGS is 0.573 Ω.

Table 6 – Wanniassa ZS Earth Grid calculated Earth Resistance in CDEGS

```
===========< G R O U N D I N G    ( SYSTEM INFORMATION SUMMARY ) >===========

 Run ID....................................: Wanniassa  Zs
 System of Units ..........................: Metric
 Earth Potential Calculations..............: Single Electrode Case
 Type of Electrodes Considered.............: Main Electrode ONLY
 Soil Type Selected........................: Multi-Layer Horizontal
 SPLITS/FCDIST Scaling Factor..............:   8.3000


     MULTI-LAYER EARTH CHARACTERISTICS USED BY PROGRAM


     LAYER  TYPE  REFLECTION     RESISTIVITY     THICKNESS
      No.         COEFFICIENT    (ohm-meter)      (METERS)
     ----- ------ ------------- ------------- -------------
       1   Air      0.00000      0.100000E+21      Infinite
       2   Soil   -0.999990       208.288      0.974990
       3   Soil   -0.945339       5.85251      0.922600
       4   Soil    0.920803       141.944          Infinite

 CONFIGURATION OF MAIN ELECTRODE
 ===============================

 Original Electrical Current Flowing In Electrode..:   1000.0     amperes
 Current Scaling Factor (SPLITS/FCDIST/specified)..:   8.3000
 Adjusted Electrical Current Flowing In Electrode..:   8300.0     amperes
 Number of Conductors in Electrode.................:   160
 Resistance of Electrode System....................:  0.57321     ohms

 SUBDIVISION
 ===========
 Grand Total of Conductors After Subdivision.:   652


 Total Current Flowing In Main Electrode......:   8300.0     amperes
 Total Buried Length of Main Electrode........:   1945.7     meters

 EARTH POTENTIAL COMPUTATIONS
 ============================

 Main Electrode Potential Rise (GPR).....:   4757.7     volts
```

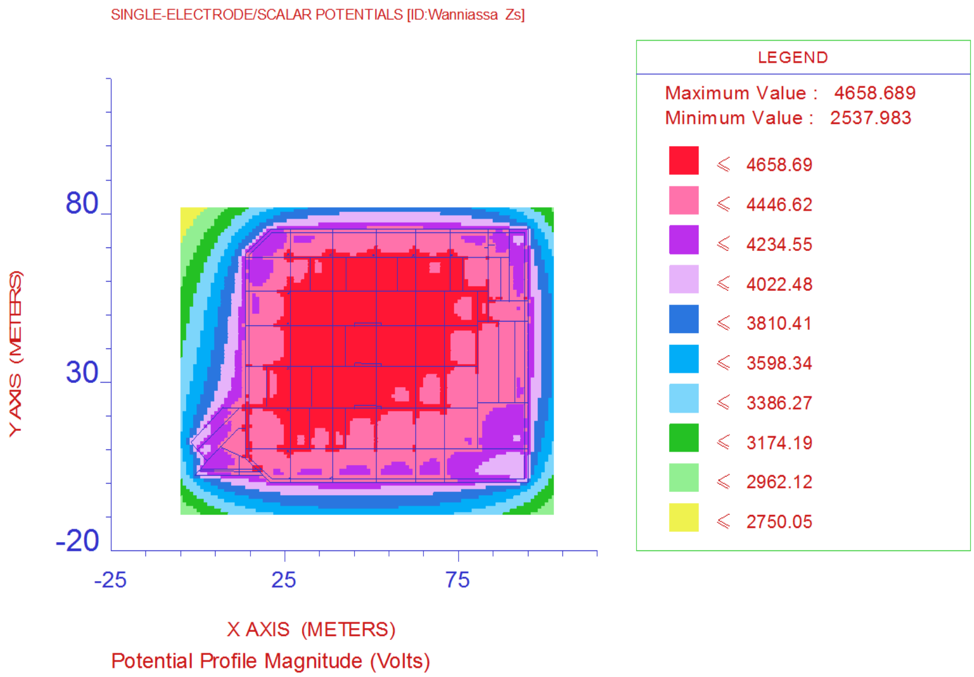
7.7. *Substation* Earth Potential Rise (EPR)

7.7.1. Earth Potential Rise (EPR).

The Calculated Ig Ground Current of 8.3 (kA) was simulated to determine the worst case EPR at the site. The worst case EPR for the substation is calculated at 4.66kV.

Figure 6 shows the scalar potentials for earth fault calculated in CDEGS.

Figure 6 – Scalar Potential Profiles



7.7.2. Telecommunication hot zone

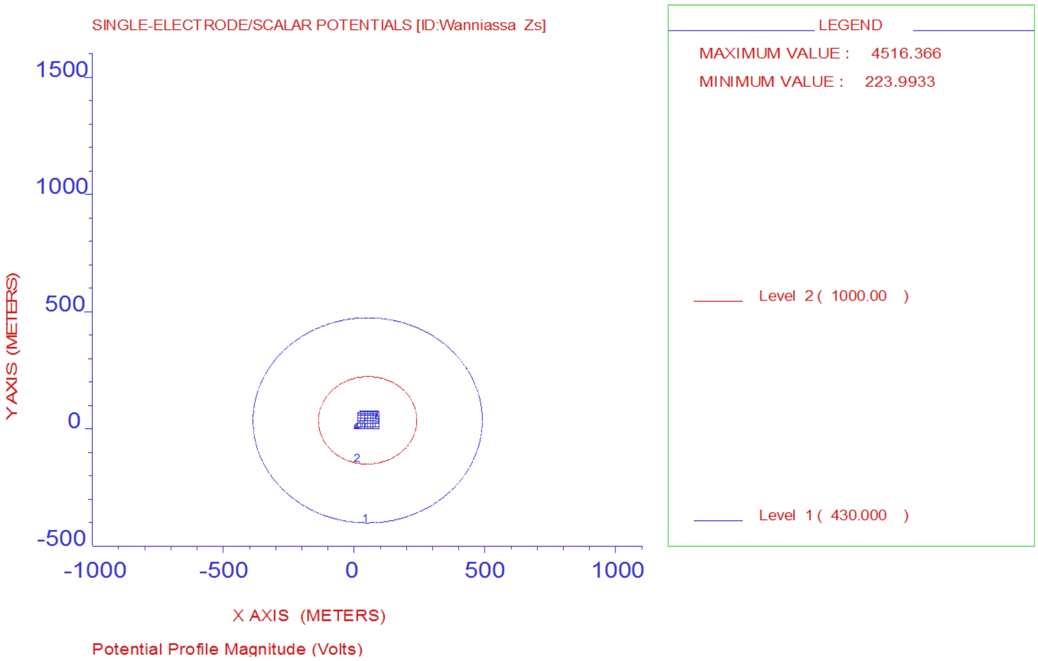
In the event of excessive earth potential rise, any nearby (permanently connected) telecommunications plants could be exposed to voltage stress. The sensitive electronic equipment could be damaged if the insulation level of the equipment is less than the EPR at that location.

The 1000 V EPR contour is approximately 150m outside Wanniassa ZS fence. Communications equipment should not be installed within this zone, unless its insulation is rated for this voltage level.

The 430V EPR contour extends approximately 350 m outside Wanniassa ZS fence. Communications equipment should not be installed within this zone, unless its insulation is rated for this voltage level.

Figure 7 shows the 430 V and 1000 V Hot Work Zone contours calculated in CDEGS.

Figure 7 - Telecommunication hot zone

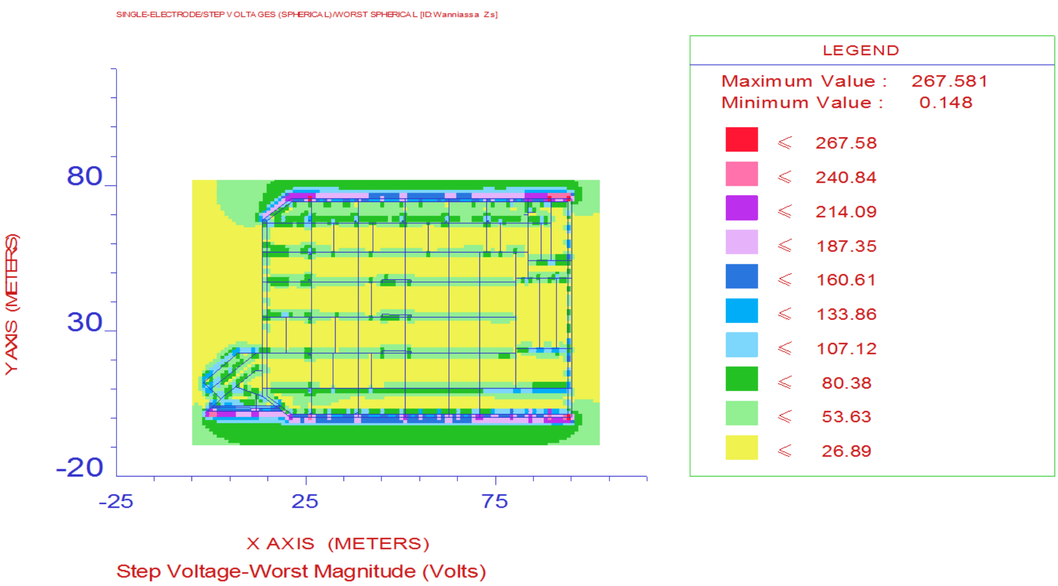


7.8. Earth Grid Step Voltage Profile in CDEGS

7.8.1. Present day maximum grid step voltages.

Using the soil resistivity test result in Section 7.4 and the earth grid model shown in Figure 2, the calculated step voltages in CDEGS at various locations, when a present day maximum earth fault of 8.3kA is flowing through the grid, are summarised in Figure 8.

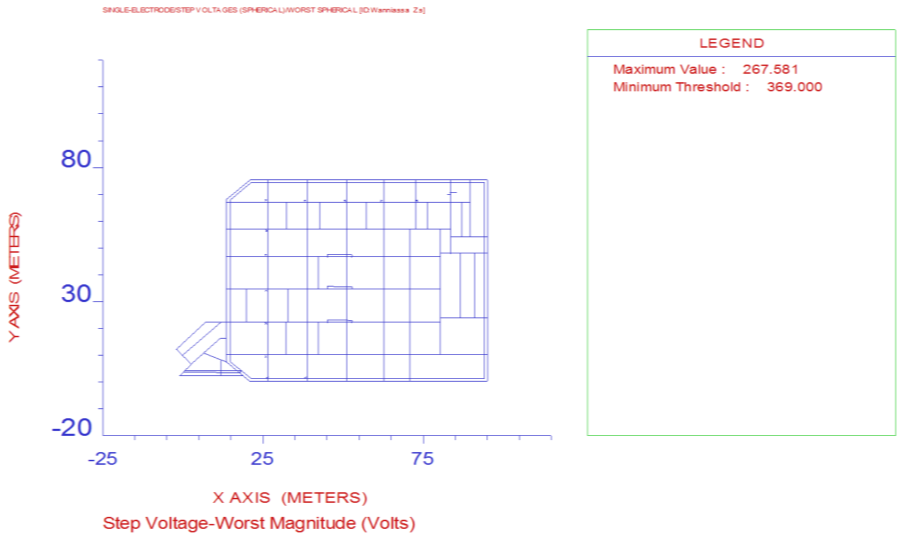
Figure 8 –Earth Grid Step Voltage Profiles in CDEGS



The safety limit for Step Voltages internal to the substation with restricted access for a 70kg body weight on yard stone is 2863V. The model indicates that these are within the permissible safe voltage limit.

The safety limit for Step Voltages external to the substation with public access for a 50kg body weight on natural ground is 369V. The model indicates that these are within the permissible safe voltage limit. This is clearly shown in Figure 9.

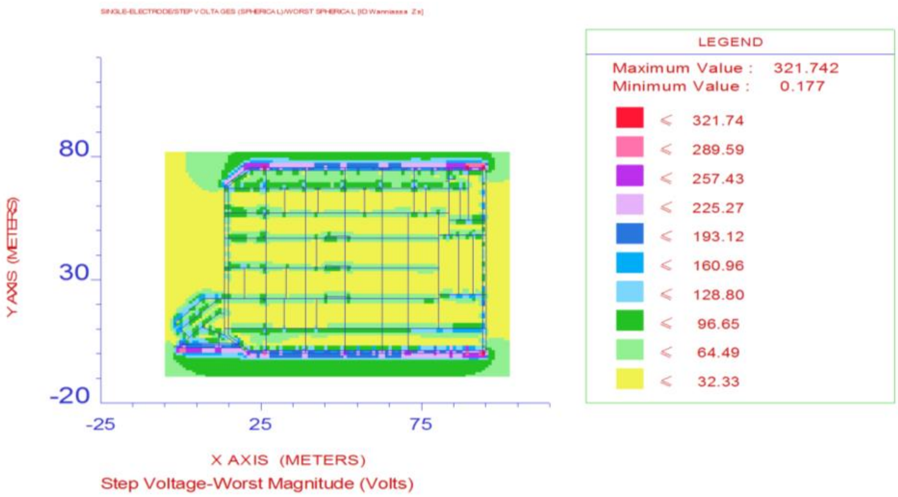
Figure 9 - Step Voltages external to the substation with public access for a 50kg body.



7.8.2. Future maximum grid step voltages.

Using the soil resistivity test result in Section 7.4 and the earth grid model shown in Figure 2, the calculated step voltages in CDEGS at various locations, when a future maximum earth fault of 9.98kA is flowing through the grid, are summarised in Figure 10.

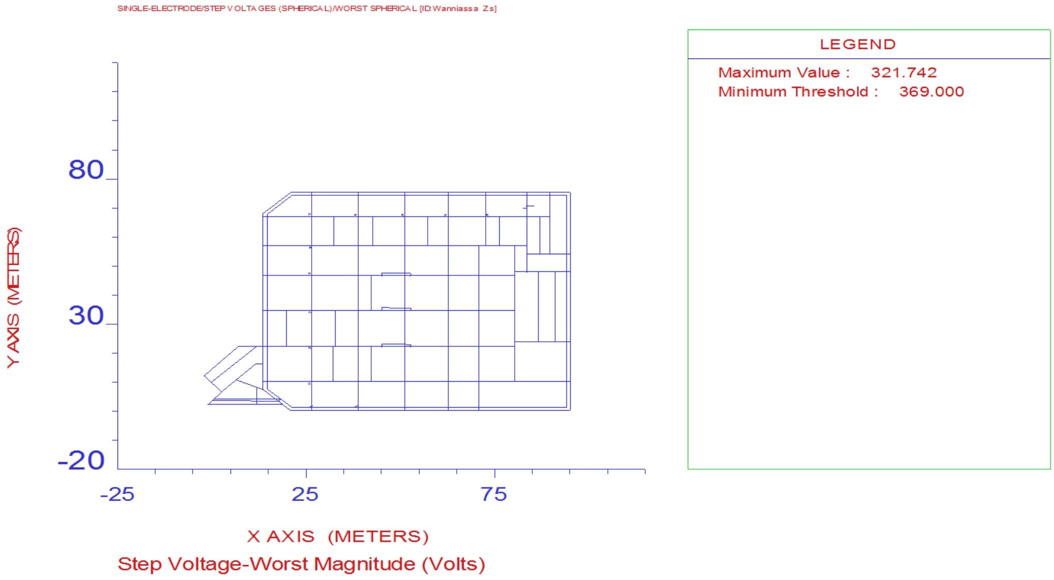
Figure 10 - Future Earth Grid Step Voltage Profiles in CDEGS



The safety limit for Step Voltages internal to the substation with restricted access for a 70kg body weight on yard stone is 2863V. The model indicates that these are within the permissible safe voltage limit.

The safety limit for Step Voltages external to the substation with public access for a 50kg body weight on natural ground is 369V. The model indicates that these are within the permissible safe voltage limit. This is clearly shown in Figure 11.

Figure 11 – Future Step Voltages external to the substation with public access for a 50kg body.

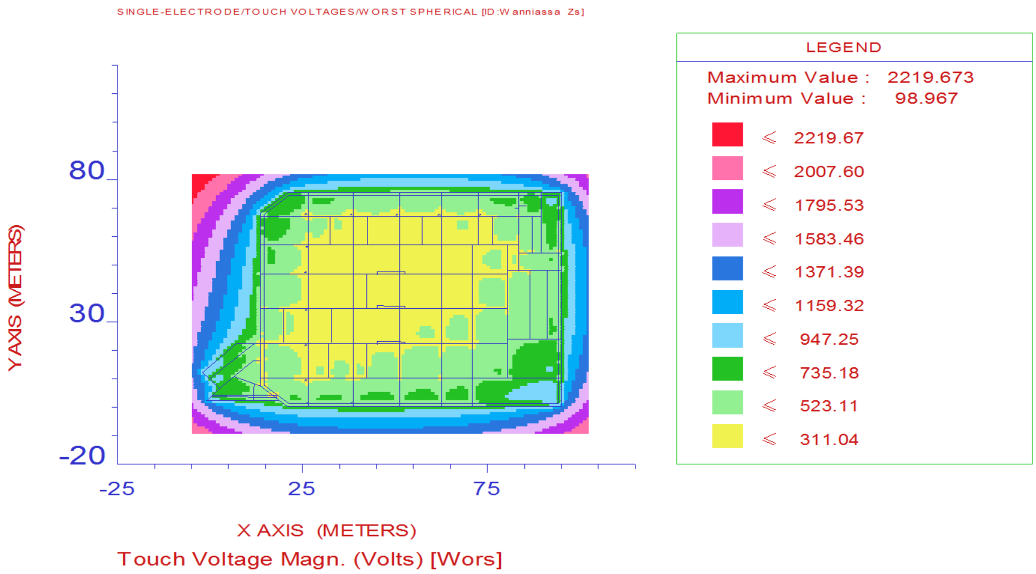


7.9. Earth Grid Touch Voltage Profile in CDEGS

7.9.1. Present day maximum grid touch voltages.

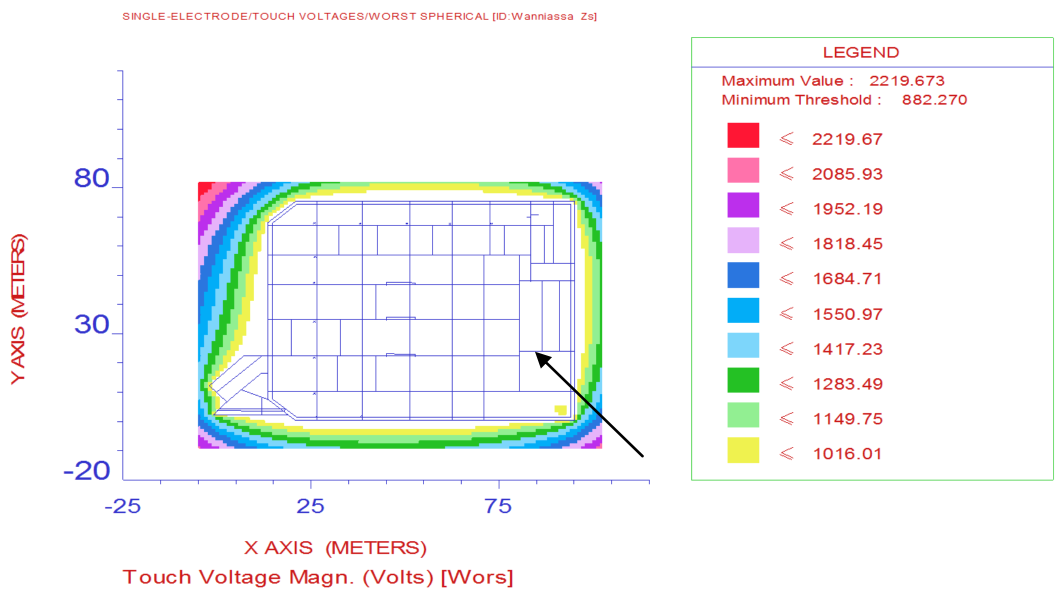
Using the soil resistivity test result in Section 7.4 and the earth grid model shown in Figure 2, the calculated touch voltages in CDEGS at various locations, when a present day maximum earth fault of 8.3kA is flowing through the grid, are summarised in Figure 12.

Figure 12 –Earth Grid Touch Voltage Profiles in CDEGS



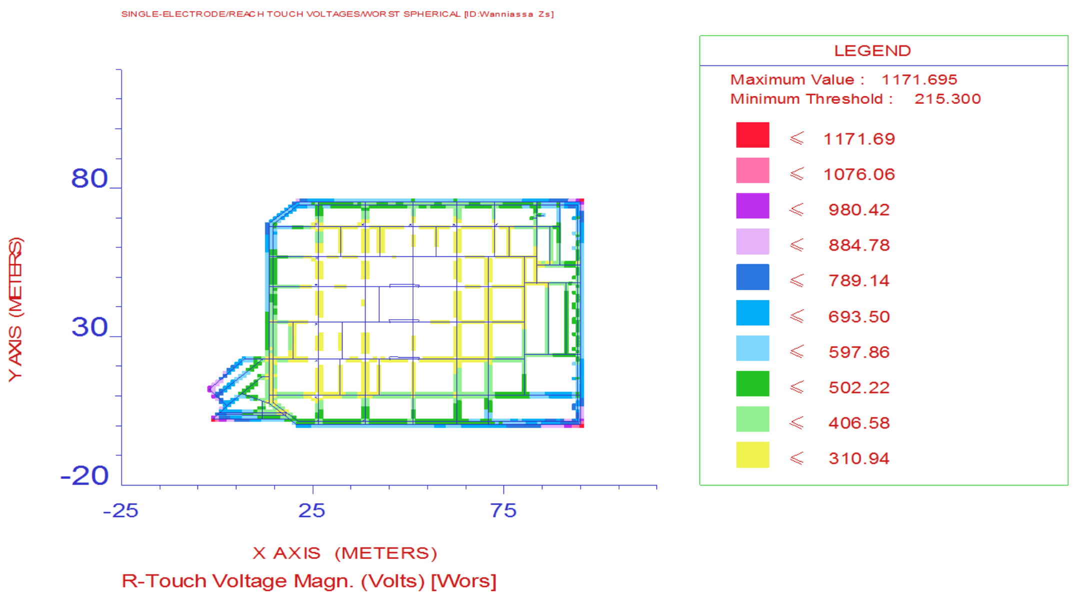
The safety limit for Touch Voltages internal to the substation with restricted access for a 70kg body weight on yard stone is 882.27V. The model indicates that there are a potential of having voltage above the limits, specifically at the north east corners of the substation. This is clearly shown in Figure 13.

Figure 13 - Potential high touch voltages internal to substation for a 70kg body.



The safety limit for Touch Voltages external to the substation with public access for a 50kg body weight on natural ground is 215.30V. The model indicates that there are a potential of having voltage above the limits along the boundary and specifically at the corners of the substation. This is clearly shown in Figure 14.

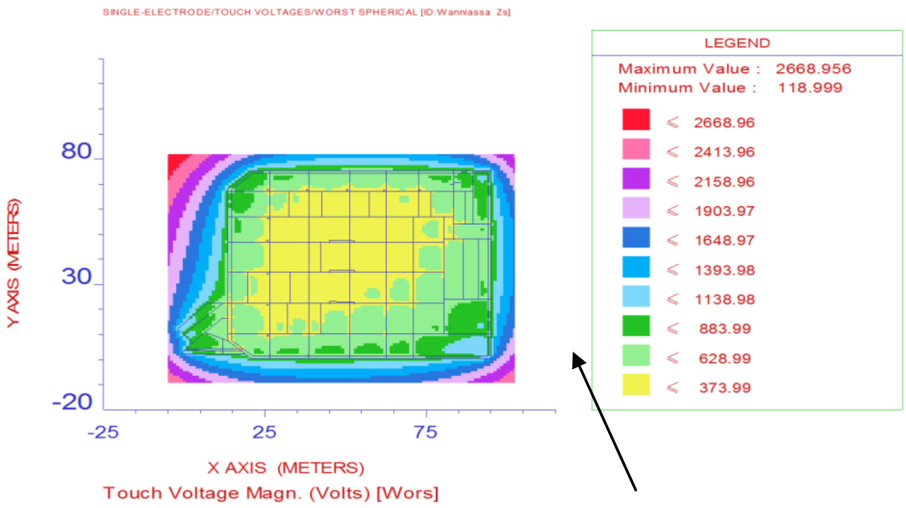
Figure 14 - Touch Voltages external to the substation with public access for a 50kg body.



7.9.1. Future maximum grid touch voltages

Using the soil resistivity test result in Section 7.4 and the earth grid model shown in Figure 2, the calculated touch voltages in CDEGS at various locations, when a future maximum earth fault of 9.98kA is flowing through the grid, are summarised in Figure 15.

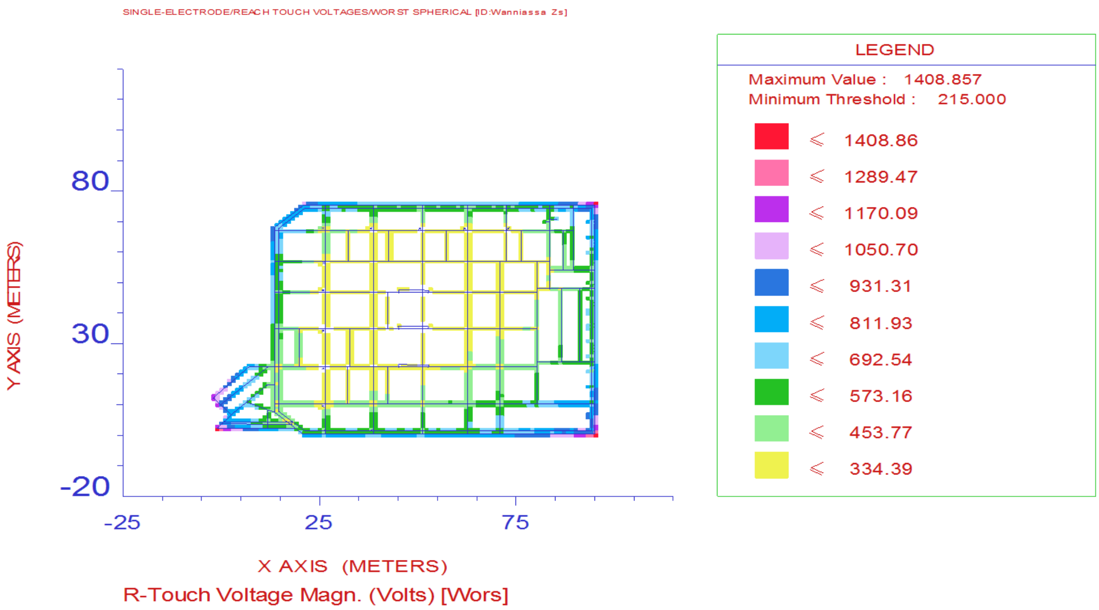
Figure 15 – Future Earth Grid Touch Voltage Profiles in CDEGS



The safety limit for Touch Voltages internal to the substation with restricted access for a 70kg body weight on yard stone is 882.27V. The model indicates that there are a potential of having voltage above the limits, specifically at the north east corners of the substation.

The safety limit for Touch Voltages external to the substation with public access for a 50kg body weight on natural ground is 215.30V. The model indicates that there are a potential of having voltage above the limits along the boundary and specifically at the corners of the substation. This is clearly shown in Figure 16.

Figure 16 - Touch Voltages external to the substation with public access for a 50kg body.



8. Grid Resistance Measurement of Wanniassa Earth Grid

The earth resistance of Wanniassa ZS earthing installation was measured using the Fall-of-Potential Method (FOP). The typical test setup is described in Figure 17.

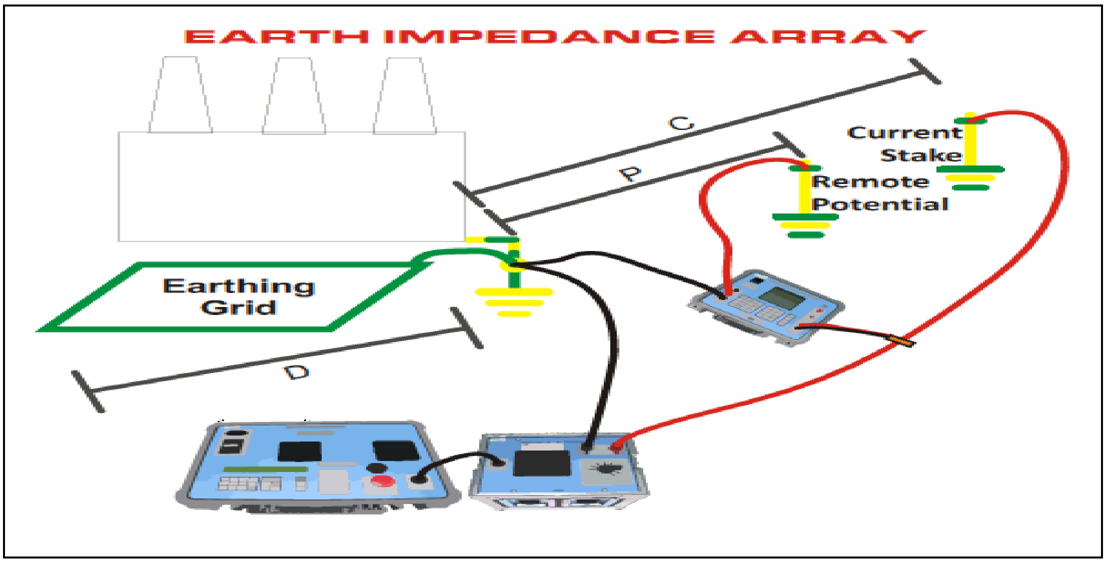


Figure 17 – Grid Resistance Measurement Typical Setup

The FOP test consisted of injecting a predetermined current into the main earth grid of Wanniassa ZS from the remote current test electrode. The offset frequency voltmeter was connected onto one of the risers of the earth grid and remote potential electrode.

The remote potential electrode was driven into the ground inline with the axis of the remote test electrode at predetermined intervals up to a distance of 500m or 75 percent of that of the test current electrodes or remote earth.

The measured voltages were the basis for calculating the apparent resistance of the earth grid using Ohm's Law. The apparent earth grid resistance includes the parallel resistances of all auxiliary earths. The substation earth grid is not tested in isolation but as part of an interconnected earth system.

8.1. Remote Earth or Current Test Probes

The test current electrode consisting of eight (8) earth stakes were installed as a remote earth for testing the earth grid of Wanniassa ZS. The electrodes were driven into the ground approximately 650 m from the northeast corner of the substation (refer to Figure 18 – Remote Earth or Test Current Electrodes for the detailed location).

Figure 18 – Remote Earth or Test Current Electrodes

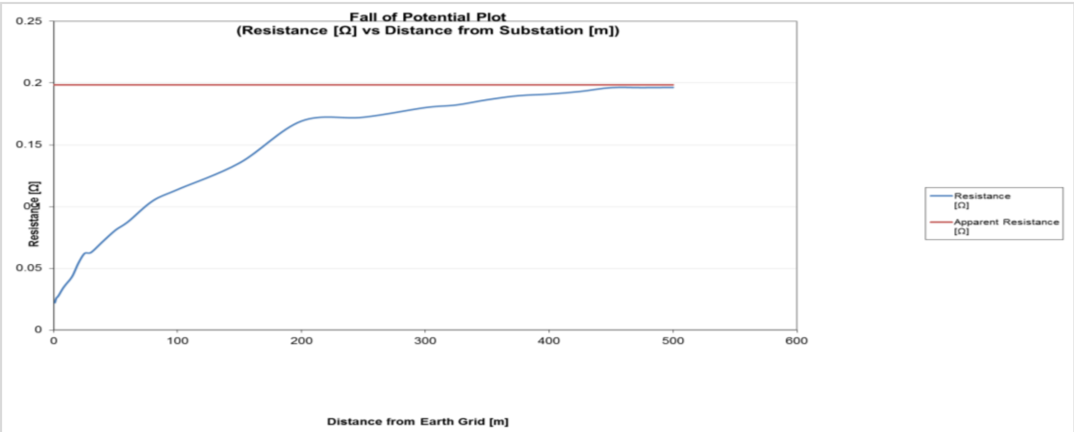
It was a sunny day when the remote earth was setup. The measured earth resistance using the Megger was 36Ω.

8.2. Fall-of-Potential Plot

The measured voltages on the remote potential electrodes, when a six (6.19) Ampere current was injected into the earth test point at Wanniassa ZS, are detailed in Appendix A. The graphical summary is shown in Figure 19.

As per Section 11.2.2 Testing Principle of ENA EG1-2006, the voltage, where the difference between two or three successive voltage readings is negligible, shall be used for calculating the resistance of the earth grid.

Figure 19 –Wanniassa ZS Earthing Fall-of-Potential Plot



The remote potential electrodes are run perpendicular to the current probes. This limits the influence of mutual coupling or other interference.

From the test results the apparent grid resistance equals 0.2Ω, which consists of local main earth grid and other remote earthing installations connected to the substation.

The grid resistance can be derived from dividing the apparent grid resistance with the % current split.

Table 7 – Estimated grid resistance

	Apparent Resistance [Ω]	% Split	Grid Resistance [Ω]
Earth Grid	0.20	49.76	0.40

There are a marked difference between the modelled grid resistance and the measure grid resistance. It is expected that this is due to auxiliary earthing that are not considered in the grid model.

9. Measured Earth Potential Rise (EPR)

9.1.1. Measured Earth Potential Rise (EPR)

The EPR is the maximum potential rise of an earthing installation, with respect to remote earth, produced when an earth fault current flows through the earthing. It is determined by multiplying the resistance of the earth grid resistance and the earth fault current.

At Wanniassa ZS and surroundings, the calculated EPR is 3.3 kV.

	Apparent Resistance [Ω]	Max Fault Current (kA)	EPR [kV]
Earth Grid	0.20	16.71	3.32

(Note: values are for present day)

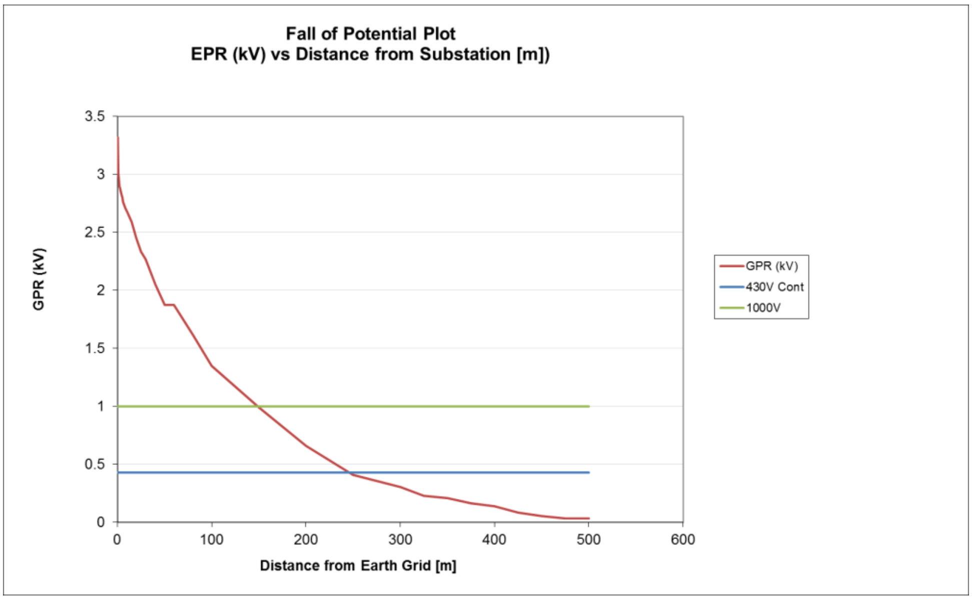
The measured value is lower than the calculated value; this however is due to the fact that the calculated grid resistance is higher than the actual measured resistance. The EPR is only significant in that it determines if the substation is classified as “hot” or “cold”. Since the EPR exceeds the allowable safety limits for step and touch it is considered as hot.

As the measured EPR exceeds the allowable step and touch voltage limits for 70 kg person tabulated in Table 5. Current injection test together with step and touch voltage measurements were required to verify if the existing earthing installation will not present a risk to the public.

9.1.2. Measured Telecommunication hot zone

When an EPR hazard occurs, any nearby (permanently connected) telecommunications plant will be exposed to voltage stress, and could be damaged (if the insulation level of the equipment is less than the EPR at that location).

The measured 1000V EPR contour extends approximately 150m outside the substation fence, and the 430V EPR contour approximately 250m.



10. Step and Touch Voltage Measurement

Using the same test current electrodes or remote earth, the earth fault scenario at Wanniassa ZS and surroundings was simulated by injecting six (6.19) Amp into the existing earth grid. The offset frequency voltmeter was used to measure the step and touch voltages around the premises.

The typical test setup for measuring the step and touch voltages is shown in Figure 20.

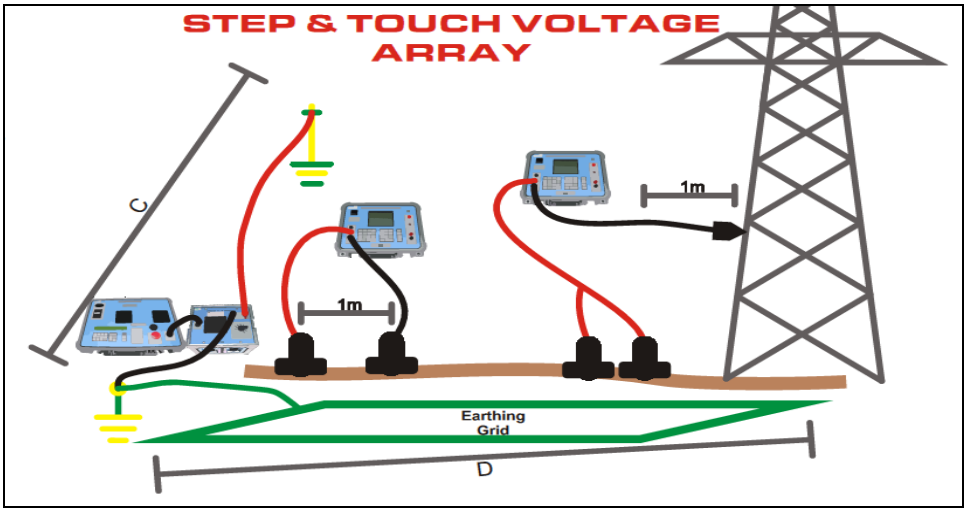


Figure 20 – Step & Touch Voltage Measurement Typical Setup

The mapped locations for the measured step and touch voltages are shown Appendix C.

10.1. Step Voltage Measurement

- There were no unsafe step voltages measured in Wanniassa ZS and surroundings.

All measurements were scaled using the maximum 132kV fault. The measurements were not assesed against future fault levels. Ground covering was considered as per existing site conditions.Safety assesment was based on the cryteria in Table 5 – Maximum Permissible Step & Touch Voltages.

Legend	
NG	Natural Ground
CR	Crushed Rock
AS	Asphalt
PA	Public Access
RA	Restricted Access

Table 8 – Step Voltages at Wanniassa ZS, Ultimate Earth Fault Currents

Date:	**14/01/2015**			**Site Supervisor:**	**T Strydom**		
Project No:	**PSD0783**			**Carried Out By:**	**C Pretorius**		
Project Desc:	**Earth Testing**						
Site Location:	**Wanniassa ZSS**			**Drawing Ref:**	**2209- 6202**		
Test Equipment:			**Frequency Voltmeter**	**Serial Numbers/ Calibration Dates:**			
6.19	**A current injection**		**16.71**	**kA Fault level**	**2699.52**	**Scaling Factor**	
Weather/Soil Conditions:							
			Sunny / Dry Soil /	**Cloudy Moist Soil**	**/ Raining / Saturated Soil**		

Test #	Description of Test Point	Surface Type	Location Type	Measured Step Voltage Open Circuit (mV)	Scaled Value (V)	Safety Limits (V)	PASS /FAIL
1.1	Gate near existing Building North	NG	PA	13.6	36.71	369.06	PASS
1	Gate near existing Building North	NG	PA	7.7	20.79	369.06	PASS
2	East corner of Substation	NG	PA	8.8	23.76	369.06	PASS
3	Double Gate	NG	PA	10	27.00	369.06	PASS
4	South end Fence corner of Substation	NG	PA	15	40.49	369.06	PASS
5	Line pole	NG	PA	10	27.00	369.06	PASS

Test #	Description of Test Point	Surface Type	Location Type	Measured Step Voltage Open Circuit (mV)	Scaled Value (V)	Safety Limits (V)	PASS /FAIL
6	Line pole	NG	PA	9.5	25.65	369.06	PASS
7	Line pole	NG	PA	2.5	6.75	369.06	PASS
8	Line pole	NG	PA	1.2	3.24	369.06	PASS
9	Line pole	NG	PA	1.2	3.24	369.06	PASS
10	Line pole	NG	PA	8.7	23.49	369.06	PASS
11	Gate	NG	PA	4.65	12.55	369.06	PASS
12	Fence	NG	PA	8.5	22.95	369.06	PASS
13	Fence	NG	PA	8	21.60	369.06	PASS
14	Fence	NG	PA	18.8	50.75	369.06	PASS
15	Fence	NG	PA	28.75	77.61	369.06	PASS
16	Gantry	CR	RA	2.4	6.48	2,863.00	PASS
17	Hand Rail	CR	RA	0	0.00	2,863.00	PASS
18	Gantry	CR	RA	1.2	3.24	2,863.00	PASS
19	Transformer Cable Structure	CR	RA	0.2	0.54	2,863.00	PASS
20	Transformer	CR	RA	2	5.40	2,863.00	PASS
21	Earthing Transformer	CR	RA	1.5	4.05	2,863.00	PASS
22	Current Transformer	CR	RA	20	53.99	2,863.00	PASS
23	Circuit Breaker	CR	RA	20	53.99	2,863.00	PASS
24	Disconnector	CR	RA	11	29.69	2,863.00	PASS
24.1	Gantry	CR	RA	36	97.18	2,863.00	PASS
24.2	Gantry	CR	RA	3	8.10	2,863.00	PASS
25	Disconnector	CR	RA	0	0.00	2,863.00	PASS
25.1	Post Insulator	CR	RA	0	0.00	2,863.00	PASS
26	Disconnector	CR	RA	6	16.20	2,863.00	PASS
27	Circuit Breaker	CR	RA	10	27.00	2,863.00	PASS
28	Current Transformer	CR	RA	3	8.10	2,863.00	PASS
29	Disconnector	CR	RA	1	2.70	2,863.00	PASS
30	Voltage Transformer	CR	RA	7	18.90	2,863.00	PASS
31	Gantry	CR	RA	2	5.40	2,863.00	PASS
32	Gantry	CR	RA	0	0.00	2,863.00	PASS
33	Post Insulator	CR	RA	2	5.40	2,863.00	PASS
34	Light Pole	CR	RA	3	8.10	2,863.00	PASS
35	Light Pole	CR	RA	3	8.10	2,863.00	PASS
36	Disconnector	CR	RA	9	24.30	2,863.00	PASS
37	Post Insulator	CR	RA	1	2.70	2,863.00	PASS
38	Disconnector	CR	RA	2	5.40	2,863.00	PASS
39	Disconnector	CR	RA	5	13.50	2,863.00	PASS

Test #	Description of Test Point	Surface Type	Location Type	Measured Step Voltage Open Circuit (mV)	Scaled Value (V)	Safety Limits (V)	PASS /FAIL
40	Circuit Breaker	CR	RA	3	8.10	2,863.00	PASS
41	Current Transformer	CR	RA	5	13.50	2,863.00	PASS
42	Gantry	CR	RA	4	10.80	2,863.00	PASS
43	Gantry	CR	RA	4	10.80	2,863.00	PASS
44	Earthing Transformer	CR	RA	0	0.00	2,863.00	PASS
45	Station Transformer	CR	RA	1	2.70	2,863.00	PASS
46	Power Transformer	CR	RA	3	8.10	2,863.00	PASS
47	Transformer Cable Structure	CR	RA	1	2.70	2,863.00	PASS
47.1	Gantry	CR	RA	1	2.70	2,863.00	PASS
47.2	Gantry	CR	RA	1	2.70	2,863.00	PASS
48	Gantry	CR	RA	1	2.70	2,863.00	PASS
49	Gantry	CR	RA	0	0.00	2,863.00	PASS
50	Transformer Cable Structure	CR	RA	4	10.80	2,863.00	PASS
51	Transformer	CR	RA	9	24.30	2,863.00	PASS
52	Station Transformer	CR	RA	2	5.40	2,863.00	PASS
53	Earthing Transformer	CR	RA	0	0.00	2,863.00	PASS
54	Gantry	CR	RA	1	2.70	2,863.00	PASS
55	Gantry	CR	RA	1	2.70	2,863.00	PASS
56	Current Transformer	CR	RA	1	2.70	2,863.00	PASS
57	Circuit Breaker	CR	RA	0	0.00	2,863.00	PASS
58	Disconnector	CR	RA	0	0.00	2,863.00	PASS
59	Post Insulator	CR	RA	1	2.70	2,863.00	PASS
60	Disconnector	CR	RA	0	0.00	2,863.00	PASS
61	Disconnector	CR	RA	2	5.40	2,863.00	PASS
62	Circuit Breaker	CR	RA	20	53.99	2,863.00	PASS
63	Current Transformer	CR	RA	10	27.00	2,863.00	PASS
64	Disconnector	CR	RA	0	0.00	2,863.00	PASS
65	Gantry	CR	RA	1	2.70	2,863.00	PASS
66	Gantry	CR	RA	0	0.00	2,863.00	PASS
67	Voltage transformers	CR	RA	0	0.00	2,863.00	PASS
68	Post Insulator	CR	RA	1	2.70	2,863.00	PASS
69		CR	RA	0	0.00	2,863.00	PASS
70	Light Pole	CR	RA	2.9	7.83	2,863.00	PASS
71	Light Pole	CR	RA	1	2.70	2,863.00	PASS
72	Roller Door	CR	RA	2	5.40	2,863.00	PASS

10.2. Touch Voltage Measurement

There was unsafe touch voltage measured in Wanniassa ZS and surroundings.

Table 9 details the test point where the excessive touch potential was measured.

Table 9 - Excessive Touch Potential Measured

Test #	Description of Test Point	PASS /FAIL
15	Fence North Western Corner	FAIL

The measurements are consistent with the CDEGS grid modeling. The model indicates that there are touch potentials having voltage above the limits along the boundary and specifically at the corners of the substation.

As remedial action it is proposed that a minimum of 1.5m wide 30mm thick asphalt is placed along the outside perimeter of the substation fence. This will ensure the touch and step voltage are mantained within the required safety limits. Table 10 shows the safety assesment with asphalt.

Table 10 - Touch point with asphalt along the fence.

Test #	Description of Test Point	Surface Type	Location Type	Measured Touch Voltage Open Circuit (mV)	Scaled Value (V)	Safety Limits (V)	PASS /FAIL
15	Fence	AS	PA	104	280.75	1,086.20	PASS

The mapped locations for the measured step and touch voltages are shown in Appendix C.

All measurements were scaled using the maximum 132kV fault. The measurements were not assesed against future fault levels. Ground covering was considered as per existing site conditions.Safety assesment was based on the criteria in Table 5 – Maximum Permissible Step & Touch Voltages.

Legend	
NG	Natural Ground
CR	Crushed Rock
AS	Asphalt
PA	Public Access
RA	Restricted Access

Table 11 – Touch Voltages at Wanniassa ZS, Maximum and Ultimate Earth Fault Currents

Date:		**14/01/2015**		**Site Supervisor:**			
Project No:		**PSD0783**		**Carried Out By:**	**T Strydom**		
Project Desc:		**Earth Testing**			C Pretorius		
Site Location:		**Wanniassa ZSS**		**Drawing Ref:**	**2209-6202**		
Test Equipment:	**Frequency Voltmeter**			**Serial Numbers:**	Calibration Dates:		
6.19	**A current injection**		**16.71**	**kA Fault level**	**2699.52**	**Scaling Factor**	
Weather/Soil Conditions:							
		Sunny Dry Soil Soil	**/ /**	**Cloudy Moist Soil**	**/ /**	**Raining Saturated**	

Test #	Description of Test Point	Surface Type	Location Type	Measured Touch Voltage Open Circuit (mV)	Scaled Value (V)	Safety Limits (V)	PASS /FAIL
1.1	Gate near existing Building North	NG	PA	55.6	150.09	215.30	PASS
1	Gate near existing Building North	NG	PA	54	145.77	215.30	PASS
2	East corner of Substation	NG	PA	70	188.97	215.30	PASS
3	Double Gate	NG	PA	16	43.19	215.30	PASS
4	South end Fence corner of Substation	NG	PA	45	121.48	215.30	PASS
5	Line pole						Wood Pole
6	Line pole						Wood Pole
7	Line pole						Wood Pole
8	Line pole	NG	PA	22	59.39	215.30	PASS
9	Line pole	NG	PA	16	43.19	215.30	PASS
10	Line pole	NG	PA	33.6	90.70	215.30	PASS
11	Gate	NG	PA	0.01	0.03	215.30	PASS
12	Fence	NG	PA	39.8	107.44	215.30	PASS
13	Fence	NG	PA	16	43.19	215.30	PASS
14	Fence	NG	PA	21	56.69	215.30	PASS
15	Fence	NG	PA	104	280.75	215.30	FAIL
16	Gantry	CR	RA	6	16.20	882.27	PASS
17	Hand Rail	CR	RA	4.6	12.42	882.27	PASS
18	Gantry	CR	RA	2	5.40	882.27	PASS
19	Transformer Cable Structure	CR	RA	3	8.10	882.27	PASS

Test #	Description of Test Point	Surface Type	Location Type	Measured Touch Voltage Open Circuit (mV)	Scaled Value (V)	Safety Limits (V)	PASS /FAIL
20	Transformer	CR	RA	1.8	4.86	882.27	PASS
21	Earthing Transformer	CR	RA	1.8	4.86	882.27	PASS
22	Current Transformer	CR	RA	50	134.98	882.27	PASS
23	Circuit Breaker	CR	RA	7	18.90	882.27	PASS
24	Disconnector	CR	RA	33	89.08	882.27	PASS
24.1	Gantry	CR	RA	56	151.17	882.27	PASS
24.2	Gantry	CR	RA	3	8.10	882.27	PASS
25	Disconnector	CR	RA	0	0.00	882.27	PASS
25.1	Post Insulator	CR	RA	0	0.00	882.27	PASS
26	Disconnector	CR	RA	1	2.70	882.27	PASS
27	Circuit Breaker	CR	RA	5	13.50	882.27	PASS
28	Current Transformer	CR	RA	3	8.10	882.27	PASS
29	Disconnector	CR	RA	1	2.70	882.27	PASS
30	Voltage Transformer	CR	RA	9	24.30	882.27	PASS
31	Gantry	CR	RA	1	2.70	882.27	PASS
32	Gantry	CR	RA	2	5.40	882.27	PASS
33	Post Insulator	CR	RA	2	5.40	882.27	PASS
34	Light Pole	CR	RA	13	35.09	882.27	PASS
35	Light Pole	CR	RA	9	24.30	882.27	PASS
36	Disconnector	CR	RA	3	8.10	882.27	PASS
37	Post Insulator	CR	RA	1	2.70	882.27	PASS
38	Disconnector	CR	RA	1	2.70	882.27	PASS
39	Disconnector	CR	RA	1	2.70	882.27	PASS
40	Circuit Breaker	CR	RA	4	10.80	882.27	PASS
41	Current Transformer	CR	RA	1	2.70	882.27	PASS
42	Gantry	CR	RA	1	2.70	882.27	PASS
43	Gantry	CR	RA	1	2.70	882.27	PASS
44	Earthing Transformer	CR	RA	1	2.70	882.27	PASS
45	Station Transformer	CR	RA	3	8.10	882.27	PASS
46	Power Transformer	CR	RA	1	2.70	882.27	PASS
47	Transformer Cable Structure	CR	RA	1	2.70	882.27	PASS
47.1	Gantry	CR	RA	1	2.70	882.27	PASS

Test #	Description of Test Point	Surface Type	Location Type	Measured Touch Voltage Open Circuit (mV)	Scaled Value (V)	Safety Limits (V)	PASS /FAIL
47.2	Gantry	CR	RA	3	8.10	882.27	PASS
48	Gantry	CR	RA	0	0.00	882.27	PASS
49	Gantry	CR	RA	1	2.70	882.27	PASS
50	Transformer Cable Structure	CR	RA	1	2.70	882.27	PASS
51	Transformer	CR	RA	13	35.09	882.27	PASS
52	Station Transformer	CR	RA	5	13.50	882.27	PASS
53	Earthing Transformer	CR	RA	5	13.50	882.27	PASS
54	Gantry	CR	RA	1	2.70	882.27	PASS
55	Gantry	CR	RA	0	0.00	882.27	PASS
56	Current Transformer	CR	RA	0	0.00	882.27	PASS
57	Circuit Breaker	CR	RA	40	107.98	882.27	PASS
58	Disconnector	CR	RA	0	0.00	882.27	PASS
59	Post Insulator	CR	RA	1	2.70	882.27	PASS
60	Disconnector	CR	RA	0	0.00	882.27	PASS
61	Disconnector	CR	RA	1	2.70	882.27	PASS
62	Circuit Breaker	CR	RA	2	5.40	882.27	PASS
63	Current Transformer	CR	RA	1	2.70	882.27	PASS
64	Disconnector	CR	RA	0	0.00	882.27	PASS
65	Gantry	CR	RA	2	5.40	882.27	PASS
66	Gantry	CR	RA	2	5.40	882.27	PASS
67	Voltage transformers	CR	RA	0	0.00	882.27	PASS
68	Post Insulator	CR	RA	0	0.00	882.27	PASS
69		CR	RA	3	8.10	882.27	PASS
70	Light Pole	CR	RA	4	10.80	882.27	PASS
71	Light Pole	CR	RA	2	5.40	882.27	PASS
72	Roller Door	CR	RA	0	0.00	882.27	PASS

10.3. Reach Touch Voltage Measurement

Reach touch potential conditions occur where hand to hand touch conditions exist. This is typicaly found between the substation fence and external structures. It is generaly accepted that structures need to be less than 2m apart in order to consider reach touch potentials.

There are no reach touch points at Wanniassa Substation

10.4. Metallic Pipelines in the Vicinity

There are no visible and/or above ground metallic pipelines in close proximity of Wanniassa ZS that the general public can access.

Referring to AS/NZS 4853:2000, the touch voltage limits for pipeline and its ancillaries for non-public access conditions is 1000 V, when an earth fault can be cleared in less than a second. Hence, any metallic pipeline buried underground should atleast be outside the 1000 V hot zone (refer to Section 9.1.2). And if not should be equipped with isolation joint(s) to prevent the transfer of dangerous EPR.

Please note that identification and verification of existing metallic pipelines in the vicinity of Wanniassa ZS is not included in the scope.

11. Earth Grid Continuity Test

The continuity test was performed on various earthing tails or connections of equipment, support structures, cubicles, access door and hand rails in Wanniassa ZS using Megger DET2/2 Auto Earth Tester 4wire resistance measurements. The riser on Transformer 3 was utilised as the reference point. Results are tabulated in Table 12 - Substation Earth Grid Continuity. The mapped locations for the Substation Earth Grid Continuity are shown in Appendix C.

There are a number of structures in the substation that have bonding resistance readings above the required limit of 10mΩ. This will require remedial action; it is proposed that the connections to the structure are disconnected, cleaned and reconnected.

Table 12 - Substation Earth Grid Continuity

Date:	**14/01/2015**	**Site Supervisor:**	**T Strydom**
Project No:	**PSD0783**	**Carried Out By:**	**C Pretorius**
Project Desc:	**Earth Testing**		
Site Location:	**Wanniassa ZSS**	**Drawing Ref:**	**2209-6001**
Test Equipment:	**DET2/2 Auto Earth Tester**	**Serial Numbers/ Calibration Dates:**	
Weather/Soil Conditions:	**Sunny / Cloudy / Raining** **Dry Soil / Moist Soil / Saturated Soil**		

Test #	Description of Test Point	Measured Resistance (Ω)	Pass/Fail (0.01>Pass)	Remarks
16	Gantry	0.01	PASS	
17	Hand Rail	0.01	PASS	
18	Gantry	0.01	PASS	
19	Transformer Cable Structure	0.01	PASS	

Test #	Description of Test Point	Measured Resistance (Ω)	Pass/Fail (0.01>Pass)	Remarks
20	Transformer	0.04	FAIL	
21	Earthing Transformer	0.01	PASS	
22	Current Transformer R	0.01	PASS	
22.1	Current Transformer W	0.01	PASS	
22.2	Current Transformer B	0.01	PASS	
23	Circuit Breaker	0.01	PASS	
23.1	Circuit Breaker Operators Earth Mat	0.01	PASS	
24	Disconnector	0.01	PASS	
24.1	Gantry	0.01	PASS	
24.2	Gantry	0.01	PASS	
24.3	Disconnector Operators Earth Mat	0.01	PASS	
25	Disconnector	0.1		
25.1a	Post Insulator R	0.01	PASS	
25.1b	Post Insulator W	0.01	PASS	
25.1c	Post Insulator B	0.01	PASS	
25.2	Disconnector Operators Earth Mat	0.01	PASS	
26	Disconnector	0.01	PASS	
26.1	Disconnector Operators Earth Mat	10	FAIL	
27	Circuit Breaker	0.01	PASS	
27.1	Circuit Breaker Operators Earth Mat	0.01	-	
28a	Current Transformer R	0.01	PASS	
28b	Current Transformer W	0.01	PASS	
28c	Current Transformer B	0.01	PASS	
29	Disconnector	0.01	PASS	
29.1	Disconnector Operators Earth Mat	0.01	PASS	
29.2	Disconnector Operators Earth Mat	0.01	PASS	
30a	Voltage Transformer R	0.01	PASS	
30b	Voltage Transformer W	0.01	PASS	
30c	Voltage Transformer B	0.01	PASS	
31	Gantry	0.01	PASS	
32	Gantry	0.01	PASS	
33	Post Insulator	0.01	PASS	
34	Light Pole	11.01	FAIL	
35	Light Pole	0.01	PASS	
36	Disconnector	0.01	PASS	
36.1	Disconnector Operators Earth Mat	0.2	FAIL	
37a	Post Insulator R	0.01	PASS	
37b	Post Insulator W	0.01	PASS	
37c	Post Insulator B	0.01	PASS	
38	Disconnector	0.01	PASS	

Test #	Description of Test Point	Measured Resistance (Ω)	Pass/Fail (0.01>Pass)	Remarks
38.1	Disconnector Operators Earth Mat	0.01	PASS	
39	Disconnector	0.01	PASS	
39.1	Disconnector Operators Earth Mat	0.01	PASS	
40	Circuit Breaker	0.01	PASS	
40.1	Circuit Breaker Operators Earth Mat	0.01	PASS	
41a	Current Transformer R	0.03	FAIL	
41b	Current Transformer W	0.01	PASS	
41c	Current Transformer B	3	FAIL	
42	Gantry	0.013	FAIL	
43	Gantry	0.01	PASS	
44	Earthing Transformer	0.01	PASS	
45	Station Transformer	0.01	PASS	
46	Power Transformer	CP	FAIL	
47	Transformer Cable Structure	0.016	FAIL	
47.1	Gantry	0.01	PASS	
47.2	Gantry	0.01	PASS	
48	Gantry	0.01	PASS	
49	Gantry	4	FAIL	
50	Transformer Cable Structure	0.01	PASS	
51	Transformer	CP	FAIL	
52	Station Transformer	0.01	PASS	
53	Earthing Transformer	0.01	PASS	
54	Gantry	0.01	PASS	
55	Gantry	0.01	PASS	
56a	Current Transformer R	22	FAIL	
56b	Current Transformer W	5.3	FAIL	
56c	Current Transformer B	0.02	FAIL	
57a	Circuit Breaker	0.01	PASS	
57b	Circuit Breaker Operators Earth Mat	0.01	PASS	
58a	Disconnector	0.01	PASS	
58b	Disconnector Operators Earth Mat	0.01	PASS	
59a	Post Insulator R	0.01	PASS	
59b	Post Insulator W	0.01	PASS	
59c	Post Insulator B	0.01	PASS	
60a	Disconnector	0.05	FAIL	
60b	Disconnector Operators Earth Mat	0.01	PASS	
61	Disconnector	0.01	PASS	
61.1	Disconnector Operators Earth Mat	OC	FAIL	
62.1	Circuit Breaker	0.01	PASS	
62.2	Circuit Breaker Operators Earth Mat	0.01	PASS	

Test #	Description of Test Point	Measured Resistance (Ω)	Pass/Fail (0.01>Pass)	Remarks
63a	Current Transformer R	0.01	PASS	
63b	Current Transformer W	0.01	PASS	
63c	Current Transformer B	0.01	PASS	
64a	Disconnector	0.01	PASS	
64b	Disconnector Operators Earth Mat	0.01	PASS	
64c	Disconnector Operators Earth Mat	0.01	PASS	
65	Gantry	0.01	PASS	
66	Gantry	0.01	PASS	
67a	Voltage transformers R	0.01	PASS	
67b	Voltage transformers W	0.01	PASS	
67c	Voltage transformers B	0.01	PASS	
68	Post Insulator	0.01	PASS	
69	NA	-	-	
70	Light Pole	0.01	PASS	
71	Light Pole	0.01	PASS	

12. Grid conductor sizing and verification

The cross sectional area of the grid conductor is directly proportional to its current carrying capacity (ampacity). The ampacity calculations conform to AS3000, and AS2067. Below is a formula from AS3000 detailing the minimum suggested conductor sizing for conductors affected by short circuits.

Earth Grid conductors were sized was checked for the worst case fault level only. As per ENA the grid conductor needs only be sized for 70% of the fault current. Based on the ampacity calculation the minimum conductor cross section required is as per Table 13 - Earth grid conductor sizing

Table 13 - Earth grid conductor sizing

Type	Ambient Temp	Final Temp	K for Copper -
Bare	40	450	216.03
Insulated	40	150	131.20
Grid Conductor	**Max Fault Current (kA)**	**Fault Clearing Time (s)**	**Min cond size req as per AS3000 (mm^2)**
Earth Grid	11.70	3	93.78
Risers	16.71	3	133.97

As per drawings 2205-6202 main grid installed consist of 19/0.101 hard drawn stranded bare copper earthing conductors and 40x3mm hard drawn copper strap laid in the ground. All high voltage equipment and transformer tanks are connected to the main earth grid using 40x3mm hard drawn copper strap earthing.

It was confirmed by visual inspection that the risers were installed in accordance with the drawings.

☝ The main grid 19/0.101 hard drawn stranded bare copper earthing conductors effectively has a cross sectional area of 98mm^2, and is adequately sized for the fault current. However there is no margined if the fault level increases in future.

The main grid 40x3mm hard drawn copper strap conductors effectively has a cross sectional area of 120mm^2, and is adequately sized for the fault current. There is adequate margined if the fault level increases in future.

☝ The 40x3mm hard drawn copper grid riser conductor effectively has a cross sectional area of 120mm^2. The conductor requires a cross sectional are of at least 133mm^2 to withstand the fault current for three second duration within the requirements of the standards. There is no remedial action required, but it could become a problem if the fault current increases in future.

13. Visual inspection and observations

Visual Inspection Notes	Photos
High touch voltages were measured between the gate and the substation north western corner.	

Visual Inspection Notes	Photos
There are a number of structures in the substation that have bonding resistance readings above the required limit. Operator's earth mats was found to be open circuit from the earth grid in some instances.	
The visual inspection was done during the testing of the substation earth grid. The yard stone was found to be in excess of 100mm thick and in a good condition. Grid risers checked and in good condition.	

14. Conclusion

This report details the result of the earthing test conducted by PSD Energy at Wanniassa Zone Substation. The objective was to measure the earth resistance of the earthing installation and to verify if there are unsafe step and touch voltages in the substation and surroundings.

Grid analysis:

PSD analysed the grid using CDEGS grid model and on site measurements. The convergence between the two methods is not as good as would be expected. This is due to inconsistencies and varying margin of error between the two methods.

The CDEGS grid analysis used only the basic grid conductors in the grid model. It does not consider all the possible auxiliary earthing that exist in the system. These include the OHEW and line pole earths as well as the concrete structures connected to the earth grid. This will produce a resultant grid resistance higher than the actual.

The fall-of-potential measures the complete/combined earthing system. The earth grid resistance of the substation is then calculated from the measured percentage current distribution. Errors in the measured current distribution will result in a grid resistance lower than the actual.

The errors will not affect the safety analysis as the step and touch measurements are not theoretical, but actual site measurements.

The modelled grid EPR is considerably higher than the measured EPR (4.7kV > 3.3kV). This is because the modelled grid resistance is higher as explained above. The effect of this is that the step and touch voltages will be scaled up in the model by 50%.

☝ The site measurements verify that the touch voltages are generally within the required limits. This however highlights the potential risk if the fault level would increase, the substation grid resistance would change or the current distribution would change.

Visual Inspection:

From the visual inspection there are a number of items that require attention, but generally the substation earthing is robust.

👎 The visual inspection was done during the testing of the substation, generally the installed earthing are in accordance with the drawings. It is observed that the fence have been upgraded, this however is not reflected on all the drawings. There is a separate fence earthing drawing. It is proposed that this information should be updated on all the substation drawings.

👍 The fence is earthed in accordance with the industry standards at every second fence post via a 40x3mm copper flat strap as per the drawings. The primary plant is earthed in accordance with the drawings via a 40x3mm copper flat strap. The earth grid was exposed by hand digging, and this verified that the main grid and connections are in good order and the conductor sizes as per drawing. The site yard stone is in good condition and well within the required 100mm layer thickness.

Step and Touch Potentials:

Step potentials were measured on the outside perimeter of the substation and the inside of the substation. The results verified that there is no dangerous step voltage inside and outside the substation.

Touch potentials were measured on the outside perimeter of the substation and the inside of the substation. Touch potentials are generally within the safety limits except at the north western corner of the fence. High touch potentials were measured at this test point.

The high touch potentials were only measured on a small section of the fence, the CDEGS model however indicates that there is a high risk of excessive touch potentials on the entire fence. The fence is 1m inside the grid. This creates a grading ring around the substation.

From the measurements, the grading ring is limiting the touch potentials within the safety limits in most parts. This could however become a problem if the fault level would increase, the substation grid resistance would change or the current distribution would change. As the EPR increases the grading ring will become less effective.

Equipment Bonding:

There are a number of structures in the substation that have bonding resistance readings above the required limit of 10mΩ. Some of the structure within the substation is painted and some of the connections seem to be onto the painted surface only. This will require remedial actions. It is advised that the connections are cleaned to ensure a copper to steel contact.

There are also a number of operators earth mats that have poor connections back to the earth grid. This will require remedial action. It is proposed that the connections to the structure are disconnected, cleaned and reconnected.

Conductor Sizing:

The substation earth grid is generally in accordance with the drawings and the conductors are in good condition.

☝ There is a concern that the132kV fault levels in the substation in the

substation are relatively high. The grid risers are just outside the requirements of the standards. This is not a safety risk, but reduces the safety margins.

In case the fault is sustained for duration in excess of 3sec, the conductors could overheat. The likely hood of this from happening is very low. Most structures have at least 2 connections, and fault clearing time is general well below 3seconds. There is no remedial action required.

Recommendations

1. Substation Fence External: It is advised that 1.5 wide 30mm thick layer of asphalt is placed around the outside of the substation fence between the western gate and north western corner, in order to mitigate the potential high touch voltages.
2. Equipment Bonding: It is advised that all the primary plant to earth grid connections are cleaned to ensure a copper to steel contact.

Testing Limitation

The safety performance of the proposed earthing is based on 132 kV 16.71 kA earth fault current with fault clearing time of 0.5 second.

Appendix A Fall-of-Potential Test Result

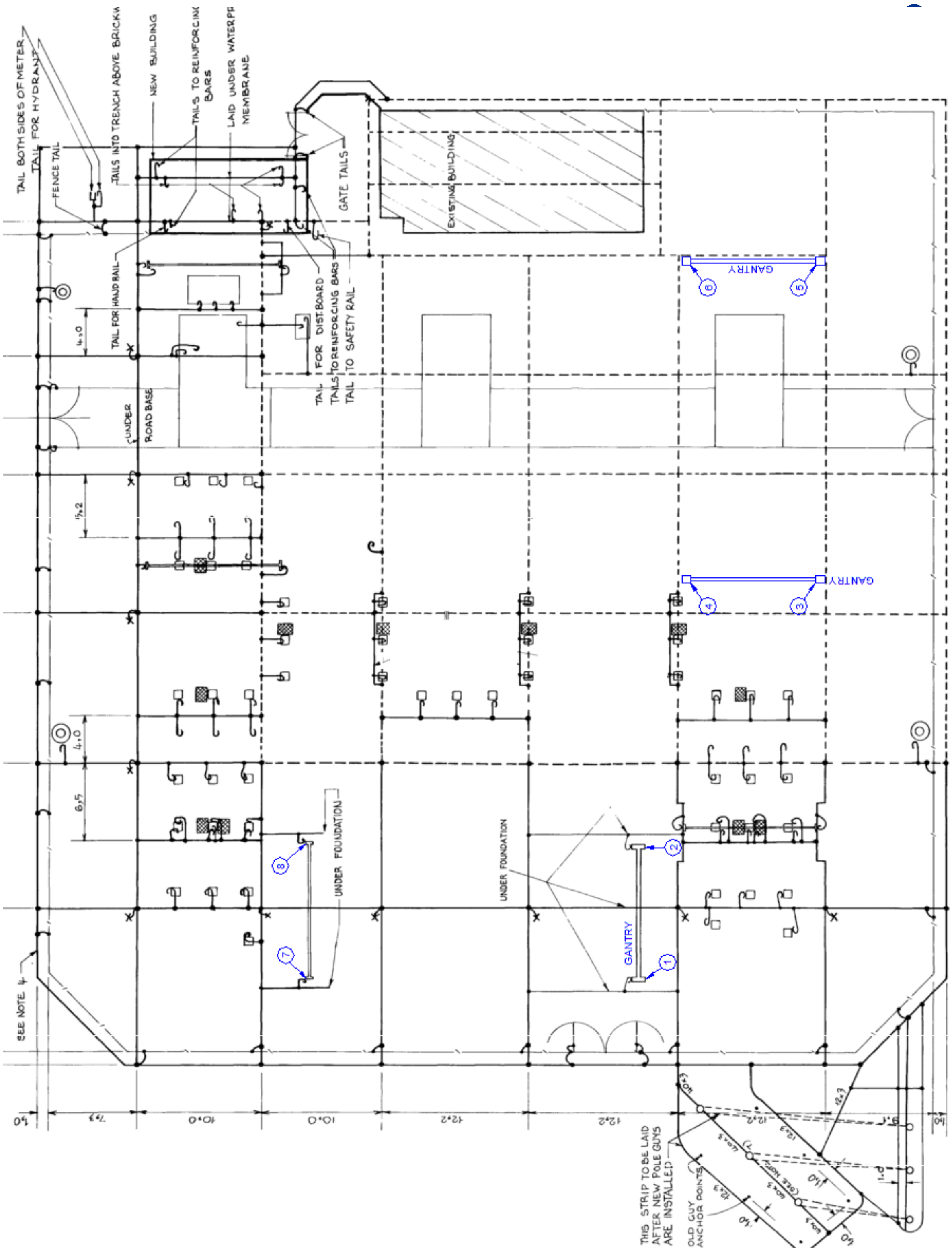
Date:	**14/01/2015**	**Site Supervisor:**	**T Strydom**
Project No:	**PSD0783**	**Carried Out By:**	**C Pretorius**
Project Desc:	**Substation Earth Testing**		
Site Location:	**Wanniassa ZSS**		
Test Equipment:	**Red Phase**	**Serial Numbers:**	
Current Injected:	**6.19**	**Calibration Date:**	
Weather/Soil Conditions:	**Sunny / Cloudy / Raining** **Dry Soil / Moist Soil / Saturated Soil**		

Distance From Grid (m)	**Measured Voltage (V)**	**Resistance [Ω]**
0	0	0
1	0.135	0.022022838
2	0.156	0.025448613
3	0.163	0.026590538
4	0.171	0.027895595
5	0.181	0.029526917
6	0.192	0.03132137
8	0.211	0.034420881
10	0.227	0.037030995
15	0.266	0.043393148
20	0.332	0.054159869
25	0.38	0.061990212
30	0.384	0.062642741
40	0.441	0.071941272
50	0.496	0.08091354

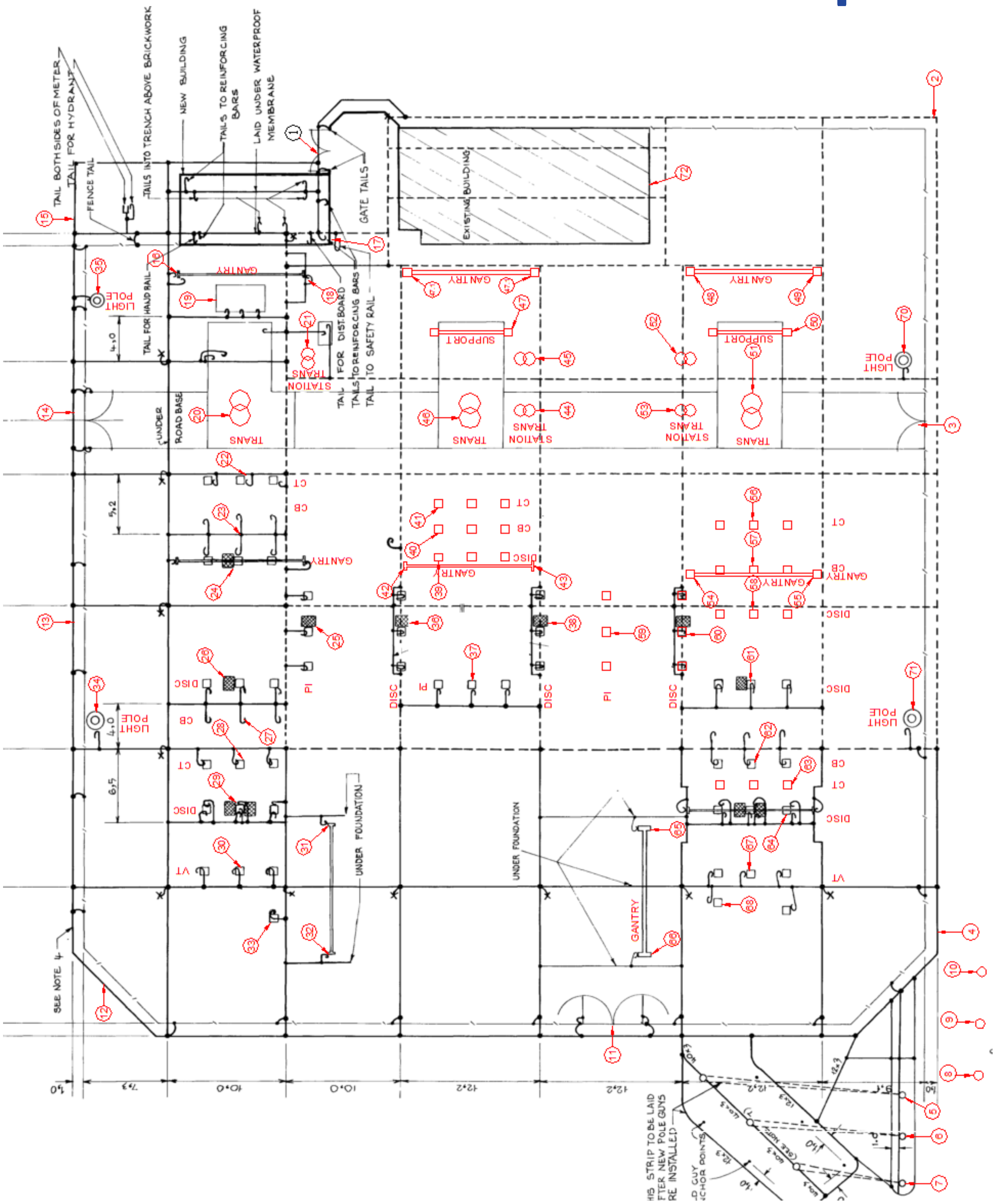
Distance From Grid (m)	Measured Voltage (V)	Resistance [Ω]
60	0.537	0.087601958
80	0.641	0.1045677
100	0.697	0.1137031
150	0.829	0.135236542
200	1.037	0.169168026
250	1.056	0.172267537

Appendix B Fault Current Distribution

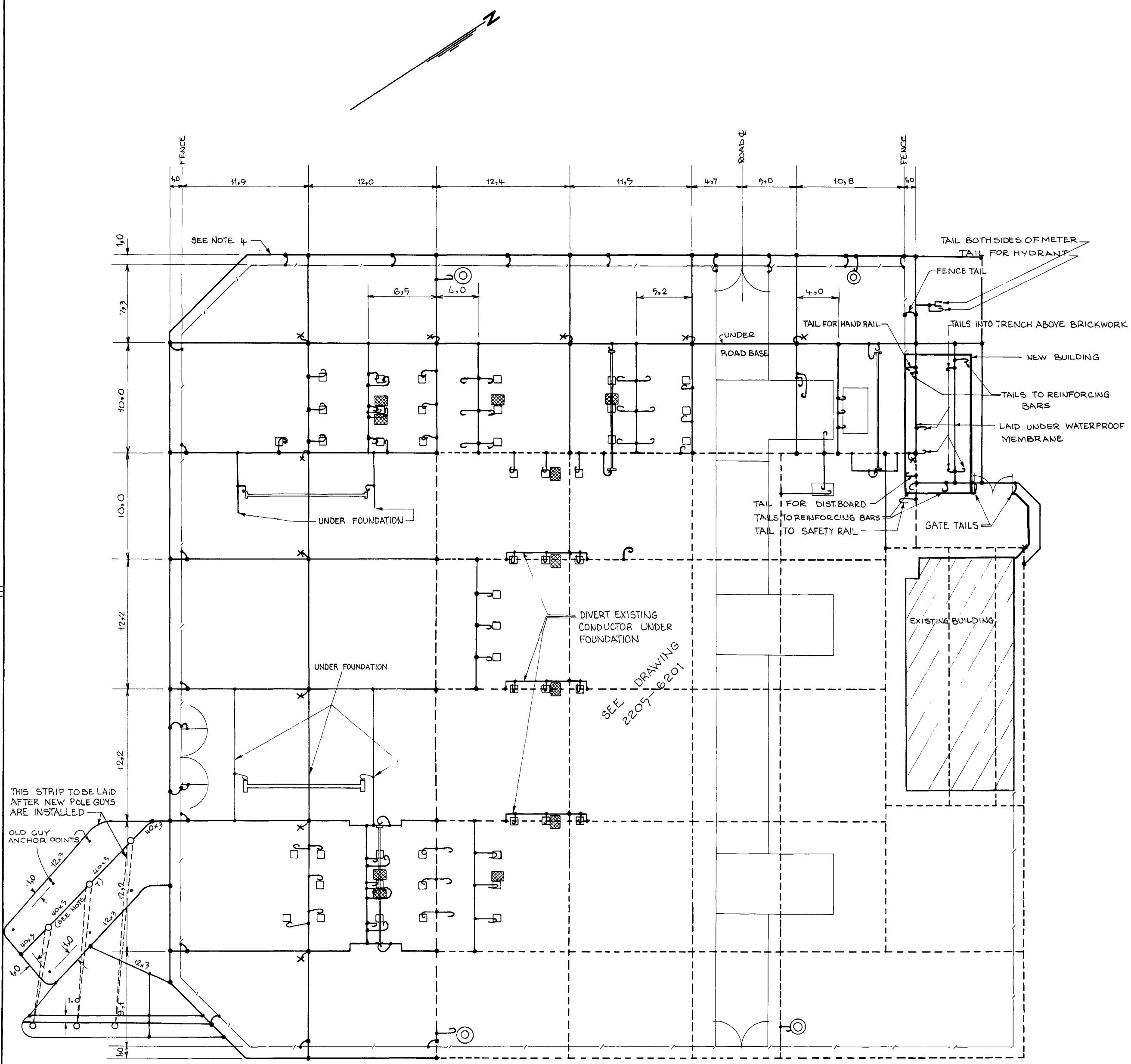
Current Distribution Measurements				
Point	**Location**	**Measured Current**	**Injected value**	**% Split**
Total	**132kV OHEW**	**3.11**	**6.19**	**50.24**
1	Gilmore Line Terminal Gantry	0.52	6.19	8.40
2	Gilmore Line Terminal Gantry	0.8	6.19	12.92
3	Over Head Bus Gantry	0.28	6.19	4.52
4	Over Head Bus Gantry	0.02	6.19	0.32
5	TX 3 Bus Gantry	0.14	6.19	2.26
6	TX 3 Bus Gantry	0.3	6.19	4.85
7	Woden Line Terminal Gantry	0.4	6.19	6.46
8	Woden Line Terminal Gantry	0.65	6.19	10.50


TAIL BOTH SIDES OF METER
TAIL FOR HYDRANT
FENCE TAIL
NEW BUILDING
EXISTING BUILDING
GATE TAILS
TAIL FOR HAND RAIL
TAIL FOR DIST. BOARD
TAILS TO REINFORCING BARS
TAIL TO SAFETY RAIL
UNDER ROAD BASE
GANTRY
GANTRY
GANTRY
UNDER FOUNDATION
UNDER FOUNDATION
SEE NOTE 4
THIS STRIP TO BE LAID AFTER NEW POLE GUYS ARE INSTALLED
OLD GUY ANCHOR POINTS

Appendix C Step, Touch Voltage and Grid Continuity Test Locations



Appendix D Wanniassa ZS Earthing Arrangement



LEGEND

- (tail symbol) 40x3 ANNEALED COPPER STRIP TAILS FOR CONNECTION TO EQUIPMENT
- (dash-dot line) 40x3 ANNEALED COPPER STRIP, UNLESS OTHERWISE STATED, BURIED 750min DEEP IN 150 WIDE TRENCH
- (solid line) 40x3 ANNEALED COPPER STRIP, UNLESS OTHERWISE STATED, BURIED 750MIN DEEP IN 150 WIDE TRENCH
- (dashed line) EXISTING EARTH GRID 19/101 HDBCC 1000 DEEP REFER TO 2205-6201
- × EARTH ELECTRODE 19/101 HDBCC OR 25x3 COPPER STRIP 3000 LONG IN DRILLED HOLES, BACKFILLED WITH BENTONITE & GYPSUM MIXTURE
- (tail symbol) 40x3 ANNEALED COPPER STRIP TAILS FOR CONNECTION TO EQUIPMENT
- (hatched square) EQUIPMENT EARTH MAT

NOTES

(1) EARTHING GRID ETC. TO BE INSTALLED BY ACTEA

(2) REF. TO ZONE SUBSTATION DESIGN INSTRUCTION FOR EARTHING Nº 2200-6200/1-6 AND ASSOCIATED DRAWINGS

(3) CARE MUST BE TAKEN TO AVOID DAMAGE TO THE EXISTING EARTH CONDUCTORS SHOWN THUS ------×

(4) THE 40x3 EARTH STRIP ON WEST SIDE OUTSIDE THE FENCE IS TO BE BURIED FLAT WITH TAILS ATTACHED BESIDE THE SEWER LINE, PRIOR TO THE TRENCH BEING BACKFILLED

(5) THREE COPPER TAILS ARE TO BE PROVIDED TO THE CENTRE SUPPORT OF THE LINE ISOLATOR

1/ FOR THE LINE ISOLATOR OPERATING DOWN ROD — FLEXIBLE TAIL TO THE EARTH GRID VIA AN EARTHING TERMINAL ON THE STRUCTURE

2/ FOR THE EARTH SWITCH OPERATING DOWN ROD — FLEXIBLE TAIL TO EARTH GRID DIRECT

3/ FOR THE EARTH SWITCH BLADE — FLEXIBLE TAILS TO EARTH GRID DIRECT

(6) THE OPERATING HANDLES OF ALL SWITCHES & ISOLATORS ARE TO BE CONNECTED VIA A 40x3 COPPER STRIP DIRECT TO THEIR OPERATING EARTH MAT — THIS CONNECTION IS TO BE VISIBLE TO THE OPERATOR

(7) EACH OVERHEAD EARTHWIRE IS TO BE BONDED TO SUBSTATION EARTHMAT VIA 40x3 COPPER STRIP

PRINTER PLEASE LEAVE 40mm FILING MARGIN

REVISIONS

A TAILS & MATS ADDED J.W.A. 28-3-80

B Earthing added to new Landing Tower & Support Column 1986. 21-1-86 MB F.H.

C ADDITIONAL SUPPORT COLUMN INSTALLED AND EARTHING ADDED 27/3/87 ADD F.H.

D SHADING REMOVED & GRADING RING INSTALLED AROUND NEW LINE POLES 30/9/87 GA

E.A.377

PROTECTION & CONTROL ENG	
PROJECT ENG	
ASSISTANT SE	19/11/79
APPROVED SUB ENG	19/11/79

A.C.T. ELECTRICITY AUTHORITY

WANNIASSA ZONE SUBSTATION
EXTENSION
EARTHING ARRANGEMENT 1979

SCALE	1:200
DRAWN	JWA
CHECKED	
DATE	16-11-79

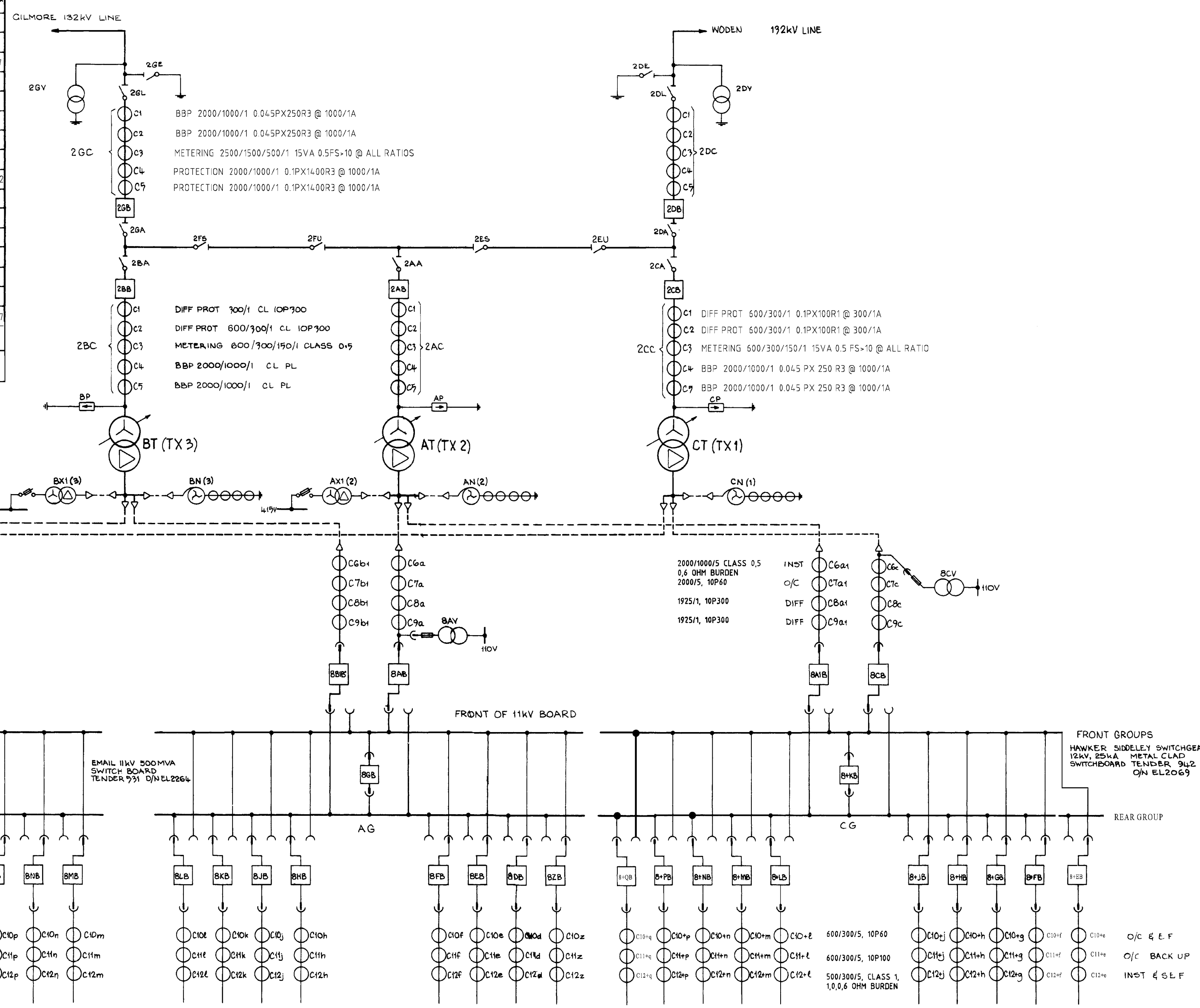
A1

2205-6202

A B C D

Appendix E Wanniassa ZS Single Line Diagram

ITEM	EQUIPMENT	MANUFACTURER	ORDER No	TENDER No
2GV, 2DV	VOLTAGE TRANSFORMER 132/√3 kV/110/√3 V	TYREE	9547	943
2GE, 2GL 2DE, 2DL	ISOLATING SWITCH & EARTHING SWITCH 145kV 3POLE HCB 2000A	STANGER & CO	3508	944
2GC, 2DC	132kV CURRENT TRANSFORMER 2500A	KONCAR		116/07
2DB, 2GB 2CB	CIRCUIT BREAKERS MIN OIL VOLUME 145kV 3PHASE 2500A HLR 145 2501E	ASEA	4857	941
2GA, 2FS, 2FU 2ES, 2EU, 2DA, 2CA	ISOLATING SWITCHES 145kV 3POLE HCB 2000A	STANGER & CO	9508	944
2AA, 2BA	ISOLATING SWITCHES 132kV 800A RD B WITHOUT EARTH SW	DICKSON PRIMER	E1601	526 ITEM 3
2BB	CIRCUIT BREAKER - SF6 GAS 145kV LTB145D1/B	ABB	PO 243094	
2AC, 2BC	CURRENT TRANSFORMERS 145kV 800A 5CORE TYPE IMBD	ASEA		529
2AB	145kV CIRCUIT BREAKER TYPE LTB SF6	ABB		362/92
AT, BT	TRANSFORMER 132/11 kV 30-50 MVA YD1 OLTC	TYREE		563
CT	TRANSFORMER 132/11kV 50MVA YD1 OLTC	TYREE		858
AX1, BX1	AUXILIARY TRANSFORMER 11,000/415 V 100 kVA	TYREE		563
AN, BN	EARTHING TRANSFORMER 11,000 V 3 PHASE	TYREE		563
CN	EARTHING TRANSFORMER 11,000 V 3 PHASE	TYREE		858
AP, BP, CP	145kV SURGE ARRESTERS TYPE PEXLM R120-YH145	ABB		
2CC	132kV CURRENT TRANSFORMER 800A	KONCAR		116/07



REVISIONS															
C REDRAWN	3RD TRANS. ADDED (CT) & 11kV BOARD EXTENDED. JWA 3-8-79	D EQUIPMENT DETAILS ADDED JWA 11-8-80	E CT 2CC TENDER No ADDED 14 5 81 GA	F TRANSFORMER N/S ADDED	G 132kV LINE DESIGNATION ALTERED 18/6/87 CA	H. METERING CT RATIO FOR 2GB AMENDED 30/10/91 ADD	J. ONE PHASE OF 2CC CHANGED 27/6/97 P.S.	K. ONE PHASE OF 2CC CHANGED 24/7/97 P.S.	L. NEW FEEDER 8-QB & 8HB ADDED MR	M 132kV CURRENT TRANSFORMERS 2CC 2DC, 2GC REPLACED 20-10-08 D.C.	N 132kV TX2 OCB REPLACED WITH GCB 30-6-10 DG	O - 132kV TX3 OCB REPLACED WITH GCB 3/05/12 FG & DS	P - ISSUED FOR CONSTRUCTION -RG 15/5/12 - FG & DS	Q - WAE - RG 3/5/12 - FG	

E.A.37

PROTECTION & CONTROL ENG	
PROJECT ENG	
ASSISTANT SE	
APPROVED SUB ENG	

A.C.T. ELECTRICITY AUTHORITY

WANNIASSA ZONE SUBSTATION
SINGLE LINE DIAGRAM

SCALE	
DRAWN	J.W.A
CHECKED	
DATE	3-8-79

A1 2205-0000 M N O P Q

PRINTER PLEASE LEAVE 40mm FILING MARGIN