Fyshwick Zone Substation Earth Grid Condition Assessment Report

PSD078319c001

Prepared for

ActewAGL

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Executive Summary

This report details the result of the earthing test conducted by PSD Energy at Fyshwick 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; it was observed that there was infrastructure installed in the substation that is not recorded on the drawings. This includes two of auxiliary transformer and the 11kV switch room.

The fence is earthed in accordance with the industry standards at every second fence post with a 38x3mm copper flat strap as per the drawings. The primary plant is earthed in accordance with the drawings via a 38x3 mm 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.

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 and the earth grid does not have a grading ring for the gate opening outwards. This presents a safety risk and it is advised that the gates are fitted with a stop to prevent them from opening outwards, alternatively a grading ring is to be installed covering the full swing of the gate.

Grid Resistance Measurement: The Fall-of-Potential Test was carried out to determine the combined earth resistance of Fyshwick 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 from the northeast corner of the substation. The voltage test probes were driven onto the ground along a similar route starting at a distance of 500m from the northeast corner of the substation.

The measured combined earth resistance of the earth system was 0.39 Ω. 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 0.45 Ω. This value is less than the resistance of the earth grid modelled in CDEGS which is 0.616 Ω.

The 11kV fault close to the substation was considered the worst case scenario for the substation. At unlikely event of an earth fault with a magnitude of 8.58 kA, the grid will produce an Earth Potential Rise (EPR) of 3.35kV.

Step and Touch Potentials: A six (6.13) 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 south eastern stern corner. The substation boundary fence is close to the neighbouring fence and high touch voltages were measured at this point. This will require remedial actions. It is advised that 1.5 wide 30mm thick layer of asphalt is placed around the substation, in order to mitigate the potential high touch voltages.

Reach touch potentials were measured between the substation boundary fence and neighbouring fencing as well as the steel stairs leading to the neighbouring building. Although the fencing and the stairs are outside the distance required for reach touch potentials, there are the potential to have voltages above the required safety limits at these points. No action is required at this point, however this needs to be considered in future expansion or fencing upgrades.

Equipment Bonding: PSD performed equipment bonding measurements on the primary infrastructure in the substation. This was done using 4wire resistance measurements. All measurements were 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. This will require remedial action; it is proposed that the connections to the structure are disconnected, cleaned and reconnected. Most of the structures within the substation are 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.

- It is also noted that the earthing connection from the overhead earth wire on the overhead line terminal poles coming into the substation is not adequately bonded to the substation earth grid. The overhead earth wires needs to have a dedicated earth connection to the substation earth grid. This will require remedial action. It is advised that a dedicated 120mm2 conductor is installed at each overhead gantry pole connected from the OHEW to the earth grid.

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 Fyshwick 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 Fyshwick 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) 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 - Fyshwick Zone Substation

FYSHWICK ZONE SUBSTATION
Cnr of Collie and Tennant Streets, Fyshwick, ACT
Google Coordinates: -35.33134, 149.180812

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 2209-0000 Fyshwick 66 kV Zone Substation Single Line Diagram

[13] Drawing 2209-6301 Fyshwick 66/11 kV Zone Substation Earthing Arrangement

[14] Drawing 2209-6001 Fyshwick 66/11 kV Zone Substation 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 Fyshwick 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

The 66kV Fyshwick ZS is delta connected and remotely earthed. The 11kV transformers are solidly earthed to the substation earth grid.

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; and
5. Soil Resistivity Test.

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 Supply Information	Fault	Maximum Earth Fault Level (kA)	Foreseeable Future Earth Fault Level (kA)	Primary Clearing Time (s)
Fyshwick 66 kV	phase to ground	6.81	8.51	0.5
Fyshwick 11 kV	phase to ground	8.58	10.73	0.5

Notes:

1. "Foreseeable Future" refers 10 to 15 years development plan for Fyshwick 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 ActewAGL.

The Fyshwick ZS 66kV distribution consists of overhead lines, which are fitted with overhead earth wire. The overhead earth wire is connected back to the substation. Generally, for internal substation faults the 66kV fault level will be the worst fault level.

The 66kV is delta connected and remotely earthed. The 66kV faults within the substation will flow back to the remote source earth via the natural earth and 66kV overhead earth wires, and will therefore produce an EPR.

The 11kV 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.

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. The 11kV faults immediately outside the substation are likely to be the highest external fault.

For 11 kV external faults, the fault current will return to substation earth grid via the earth cable and/or natural earth (ground), and therefore will produce an EPR. It is likely that the fault impedance at overhead lines will be high for external 11kV faults, which could reduce the fault current; this is ignored in this study. The error introduces an additional margin of safety.

As the 11 kV earth fault level is higher than 66 kV, the Fyshwick 11 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 verify the earthing contribution from the various auxiliary paths. Please see Appendix B for site measurements. Table 2 – Present Current Distribution shows the percentage of current measured in the various auxiliary paths.

Table 2 – Present Current Distribution

	Max Fault Current (kA)	Calculated Ig Ground Current (kA)	% Split
Earth Grid	8.58	7.41	86.35
66kV OHEW	8.58	1.17	13.65

Table 3 - Future Current Distribution

	Max Fault Current (kA)	Calculated Ig Ground Current (kA)	% Split
Earth Grid	10.30	8.89	86.35
66kV OHEW	10.296	1.41	13.65

The current split testing provides a conservative approximation of the 66kV OHEW performance as well as other impedances. From the test results, an estimate of the existing grid resistance of Fyshwick 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 **7.41kA** and the Future ground current is **8.89kA.** 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.

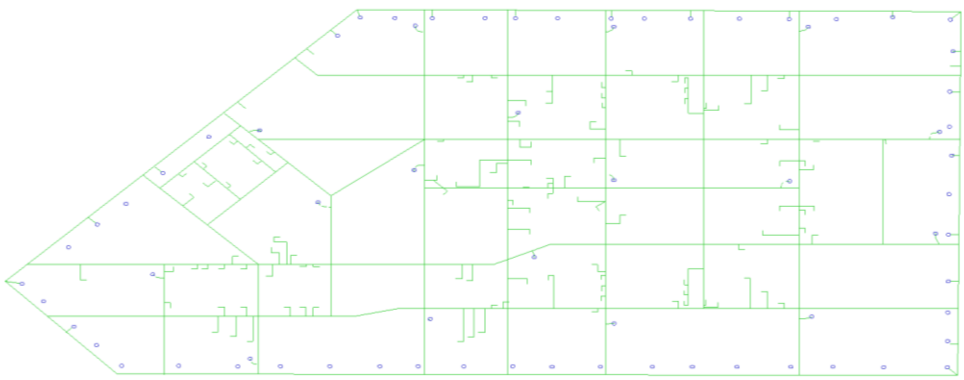
The RESAP module was used to generate the multi-layer soil model using soil resistivity test data collected at site.

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 Fyshwick ZS, as shown in drawing 2209-6301, 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 37/2.25 mm copper buried at a nominal depth of 750 mm below ground and laid in a mesh configuration. Drawing 2209-6301 shows the arrangement of the earth conductors installed at Fyshwick ZS, refer to Appendix E.

Earth Rods:

Earth rods were model in accordance with drawing 2209-3601, 17 off 13 mm diameter 3 metre long copper clad electrodes were installed in the substation earth grid.

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 and the earth grid does not have a grading ring for the gate opening outwards. This presents a safety risk and it is advised that the gates are fitted with a stopper to prevent it from opening outwards. Alternatively, a grading ring is to be installed covering the full swing of the gate.

7.4. Soil Resistivity Model

A soil resistivity tests were carried out by PSD south of Fyshwick using the Wenner 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: N-S

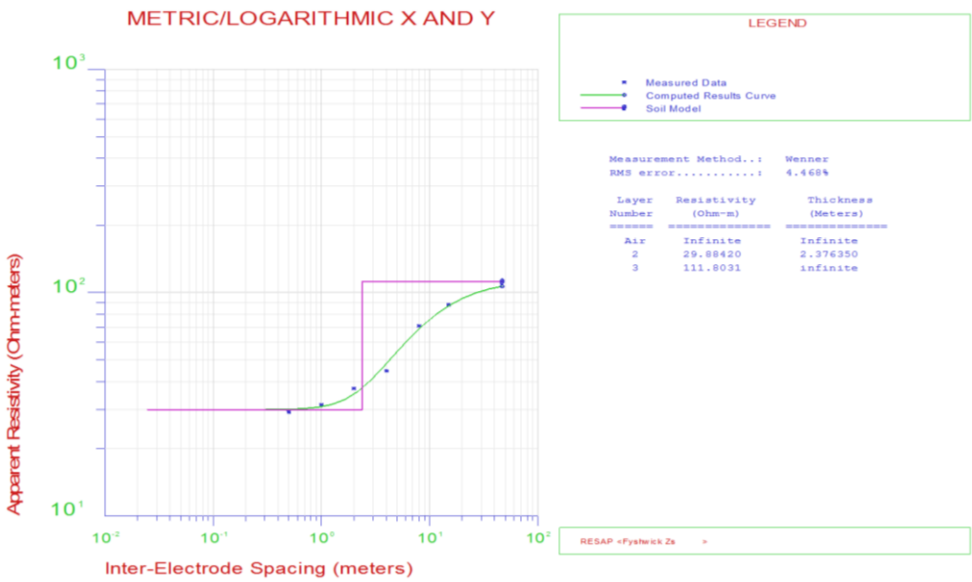


Figure 5 - Traverse B: E-W

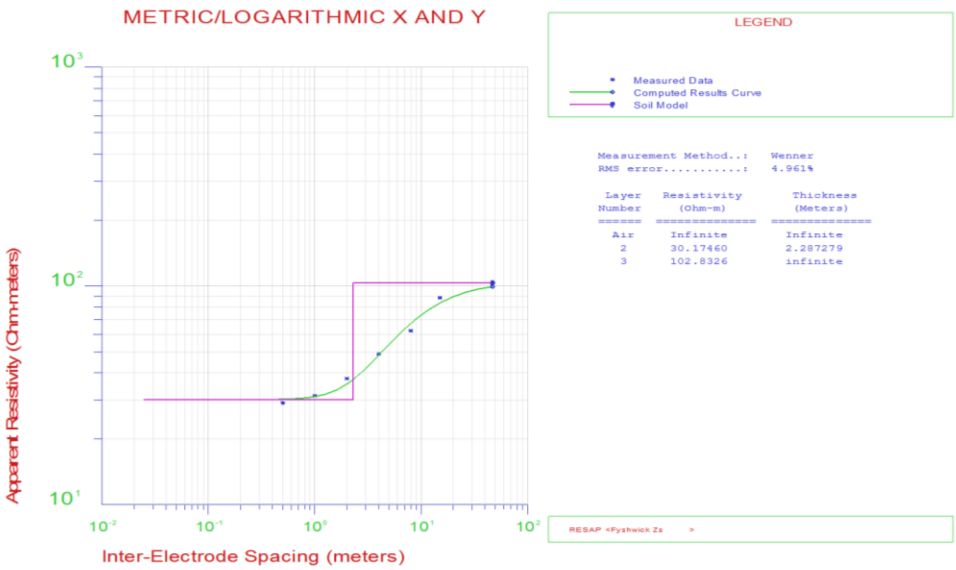


Table 4 - Fyshwick Average Soil Resistivity

Layer	Resistivity	Thickness	Coefficient	Contrast
1	infinite	infinite	0	1
2	30.0294	2.331815	-1	3E-19
3	107.31785	infinite	0.56222	3.57455

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 in the vicinity of Fyshwick 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 30Ω-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) = 30 *Ω.m*	193.58	171.43	262.00	232.02
Aggregates = 3000 Ω.m	2097.10	647.31	2838.32	876.10
Concrete/Asphalt = 10000 Ω.m	3740.59	1058.18	5062.69*	1432.20
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, the calculated earth resistance of Fyshwick ZS earthing in CDEGS is 0.61622 Ω.

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

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

 Run ID......................................: Fyshwick 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................:   9.2600



     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       30.0294       2.33181
       3   Soil    0.562723       107.318          Infinite
1


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

 Original Electrical Current Flowing In Electrode..:   1000.0     amperes
 Current Scaling Factor (SPLITS/FCDIST/specified)..:   9.2600
 Adjusted Electrical Current Flowing In Electrode..:   9260.0     amperes
 Number of Conductors in Electrode.................:   486
 Resistance of Electrode System....................:  0.61622     ohms



 SUBDIVISION
 ===========
 Grand Total of Conductors After Subdivision.:  1120


 Total Current Flowing In Main Electrode......:   9260.0     amperes
 Total Buried Length of Main Electrode........:   1281.2     meters



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

 Main Electrode Potential Rise (GPR).....:   5706.2     volts
```

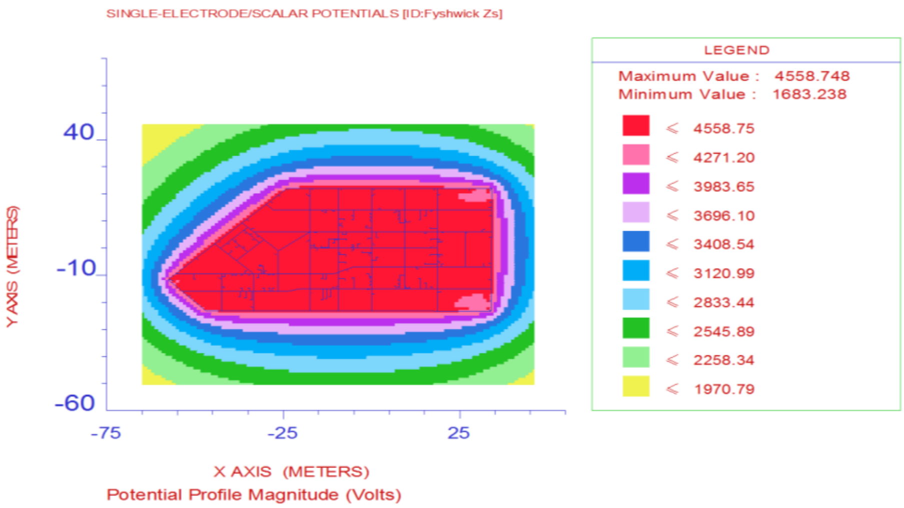
7.7. *Substation* Earth Potential Rise (EPR)

7.7.1. Earth Potential Rise (EPR).

The Calculated Ig Ground Current of 7.41 (kA) was simulated to determine the worst case EPR at the site. The worst case EPR for the substation is calculated at 4.58kV.

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

Figure 6 – Scalar Potential Profiles



7.7.2. Telecommunication hot zone

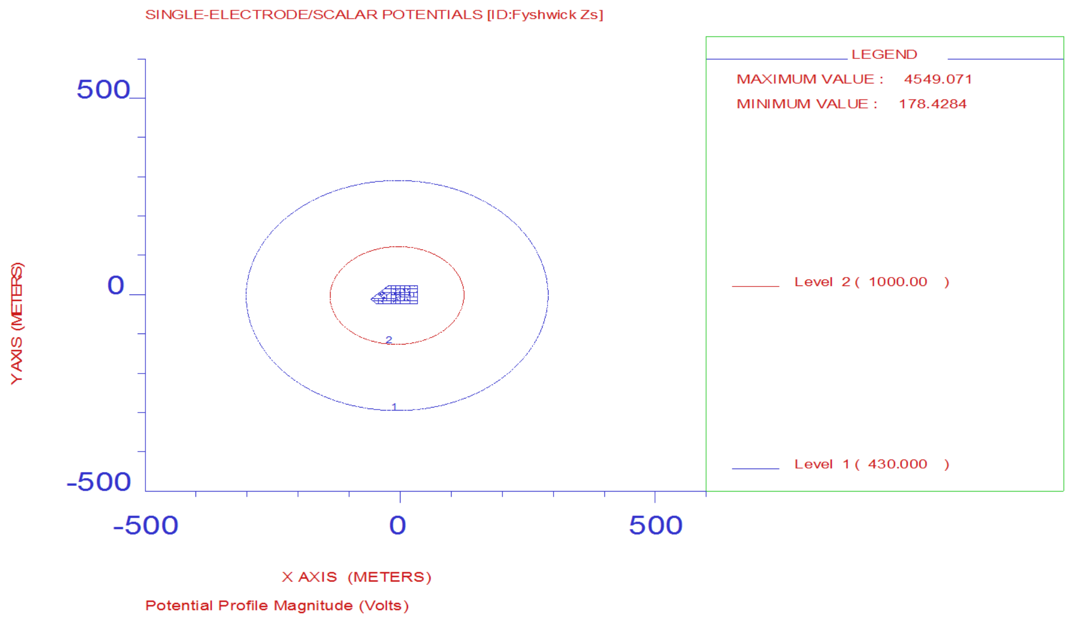
In the of excessive earth potential rise, any nearby (permanently connected) telecommunications plants could be exposed to voltage stress. The sensitive electronic equipment could be damaged if the insulation level of the equipment is less than the EPR at that location.

The 1000 V EPR contour is approximately 100m outside Fyshwick 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 300 m outside Fyshwick ZS fence. Communications equipment should not be installed within this zone, unless its insulation is rated for this voltage level.

Figure 7 - Telecommunication hot zone shows the 430 V and 1000 V Hot Work Zone contours calculated in CDEGS

Figure 7 - Telecommunication hot zone

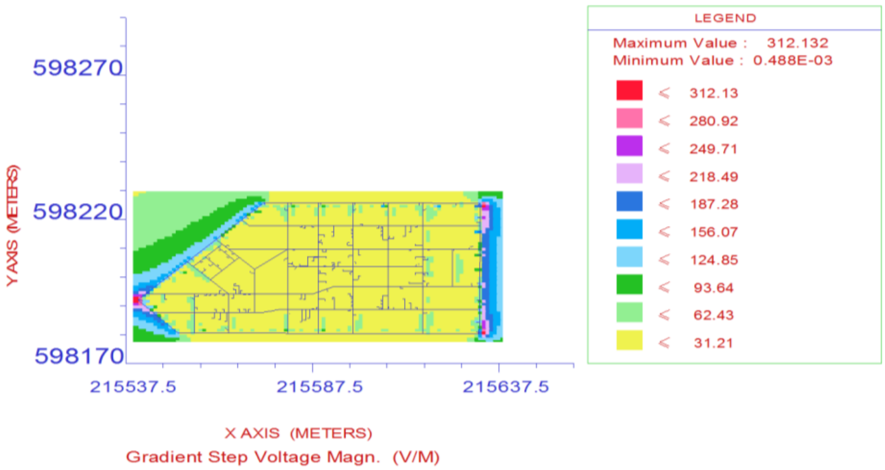


7.8. Earth Grid Step Voltage Profile in CDEGS

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 7.41kA is flowing through the grid, are summarised in Figure 8.

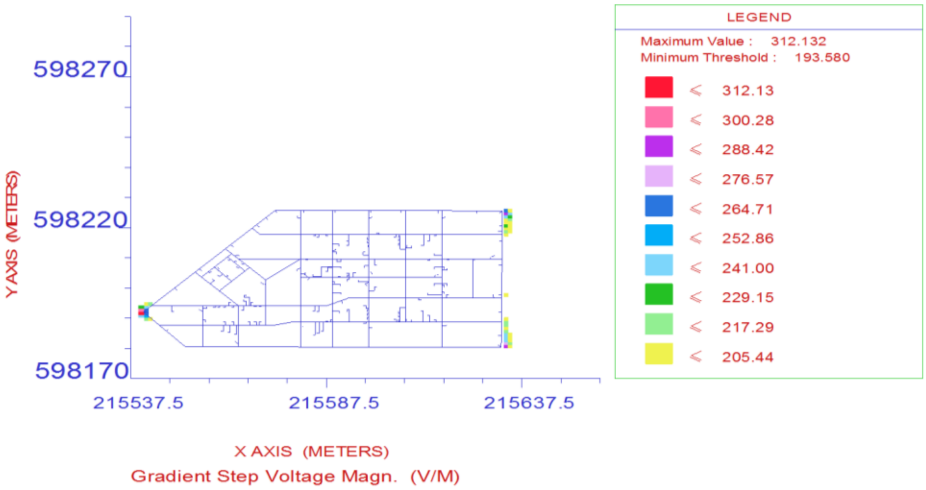
Figure 8 –Earth Grid Step Voltage Profiles in CDEGS



The safety limit for Step Voltages internal to the substation with public access for a 70kg body weight on yard stone is 2838V. 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 193.58V. The model indicates that there are a potential of having voltage above the limits at the corners of the substation. This is clearly shown in Figure 9.

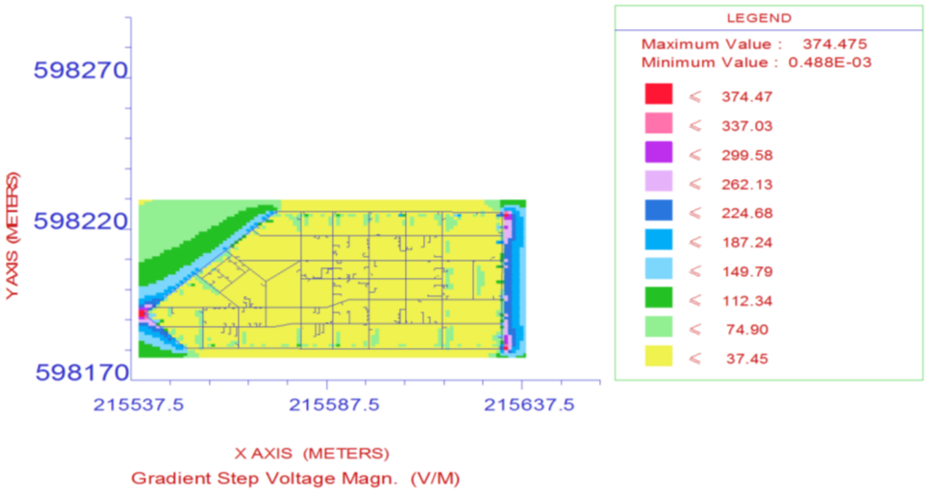
Figure 9 - Step Voltages external to the substation with public access for a 50kg body.



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 maximum earth fault of 8.89kA is flowing through the grid, are summarised in Figure 10.

Figure 10 - Future Earth Grid Step Voltage Profiles in CDEGS

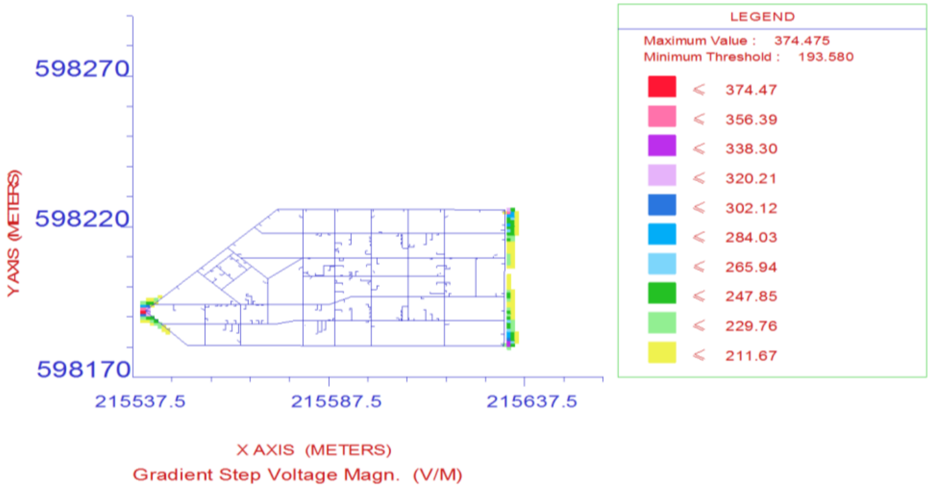


The safety limit for Step Voltages internal to the substation with public access for a 70kg body weight on yard stone is 2838V. The model indicates that these are within the permissible safe voltage limit.

The safety limit for Step Voltages external to the substation with public access for a 50kg body weight on natural ground is 193.58V. The model indicates that there are a potential of having voltage above the limits at the corners of the substation. This is clearly shown in

Figure 11.

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

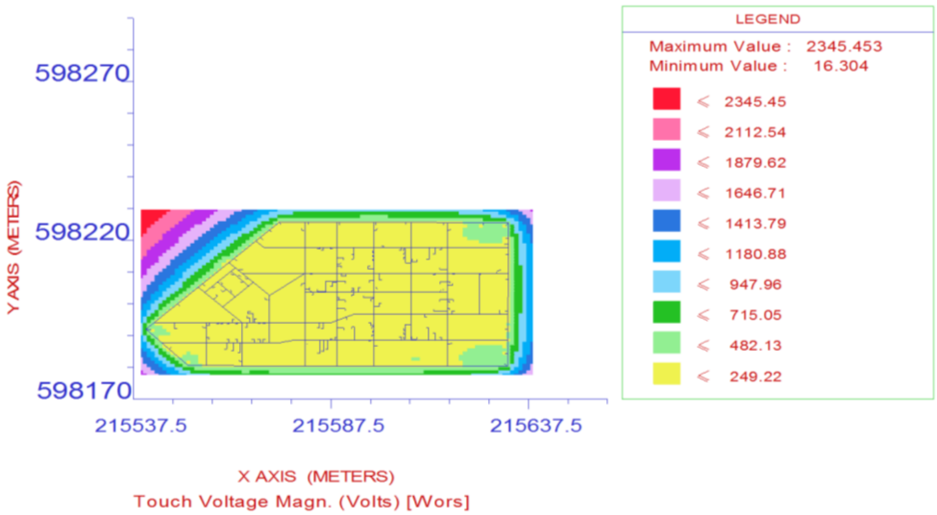


7.9. Earth Grid Touch Voltage Profile in CDEGS

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 7.41kA is flowing through the grid, are summarised in Figure 12.

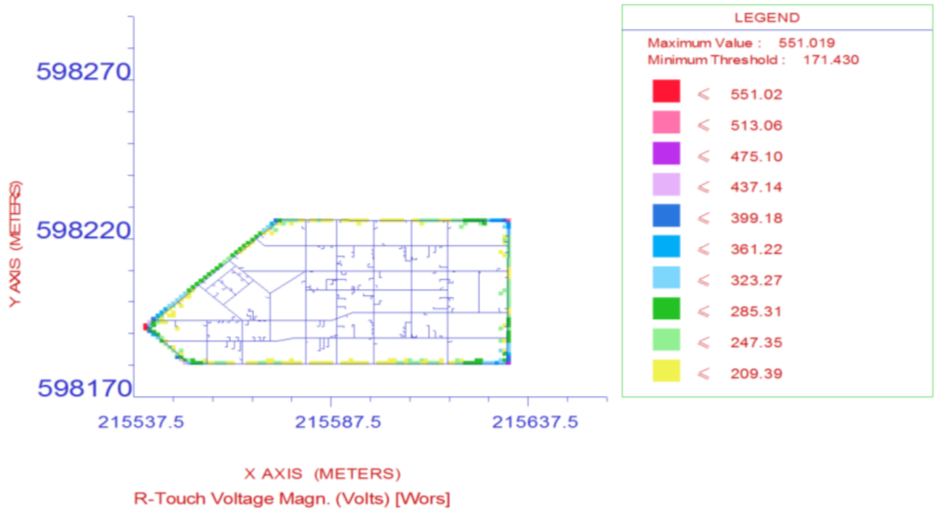
Figure 12 –Earth Grid Touch Voltage Profiles in CDEGS



The safety limit for Touch Voltages internal to the substation with restricted access for a 70kg body weight on yard stone is 876.10V. The model indicates that these are within the permissible safe voltage limit.

The safety limit for Touch Voltages external to the substation with public access for a 50kg body weight on natural ground is 171.43V. 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 13.

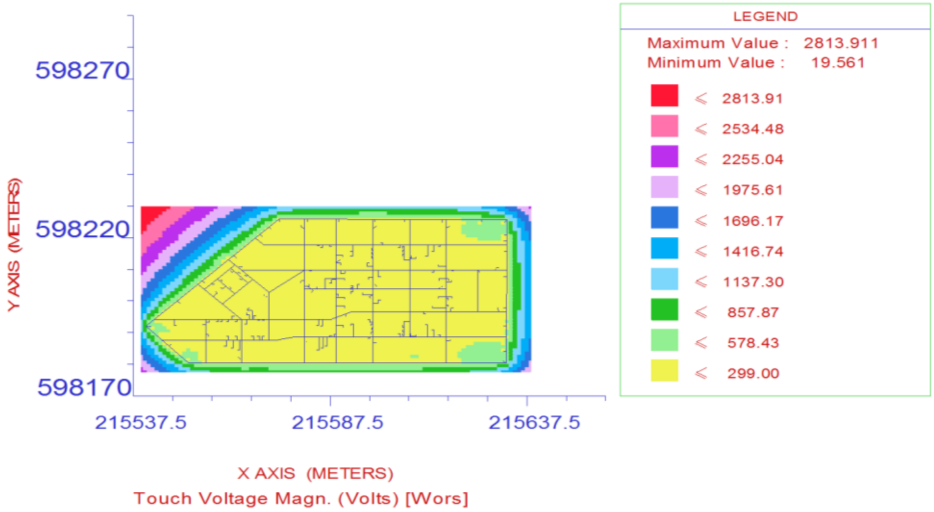
Figure 13 - Touch Voltages external to the substation with public access for a 50kg body.



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 8.89kA is flowing through the grid, are summarised in Figure 14.

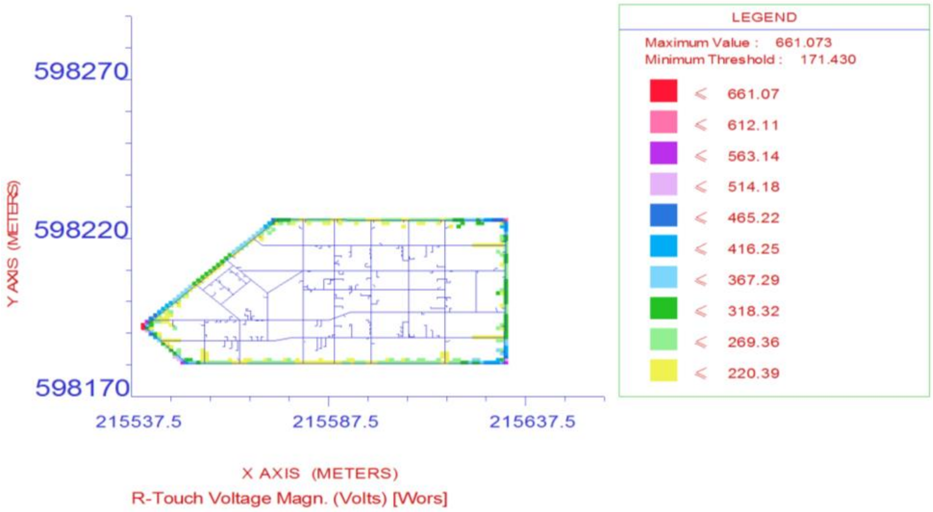
Figure 14 – Future Earth Grid Touch Voltage Profiles in CDEGS



The safety limit for Touch Voltages internal to the substation with public access for a 70kg body weight on yard stone is 876.10V. The model indicates that these are within the permissible safe voltage limit.

The safety limit for Touch Voltages external to the substation with public access for a 50kg body weight on natural ground is 171.43V. 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 15.

Figure 15 - Touch Voltages external to the substation with public access for a 50kg body.



8. Grid Resistance Measurement of Fyshwick Earth Grid

The earth resistance of Fyshwick ZS earthing installation was measured using the Fall-of-Potential Method (FOP). The typical test setup is described in Figure 16.

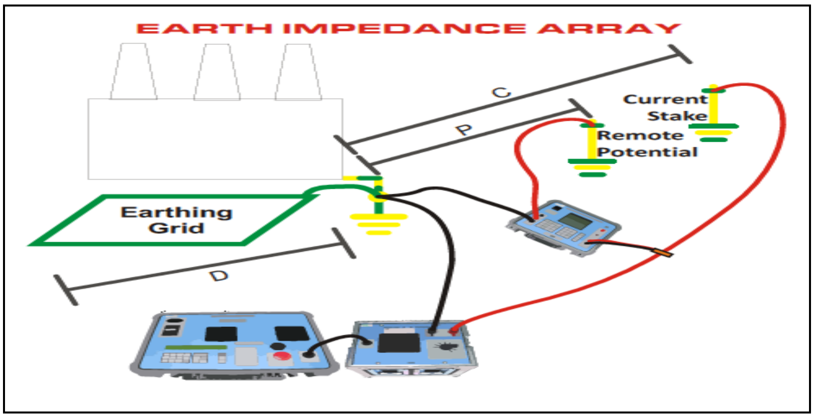


Figure 16 – Grid Resistance Measurement Typical Setup

The FOP test consisted of injecting a predetermined current into the main earth grid of Fyshwick 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 Fyshwick ZS. The electrodes were driven into the ground at a vacant lot across the Tennant St; approximately 650 m from the northeast corner of the substation (refer to Figure 17 – Remote Earth or Test Current Electrodes for the detailed location).

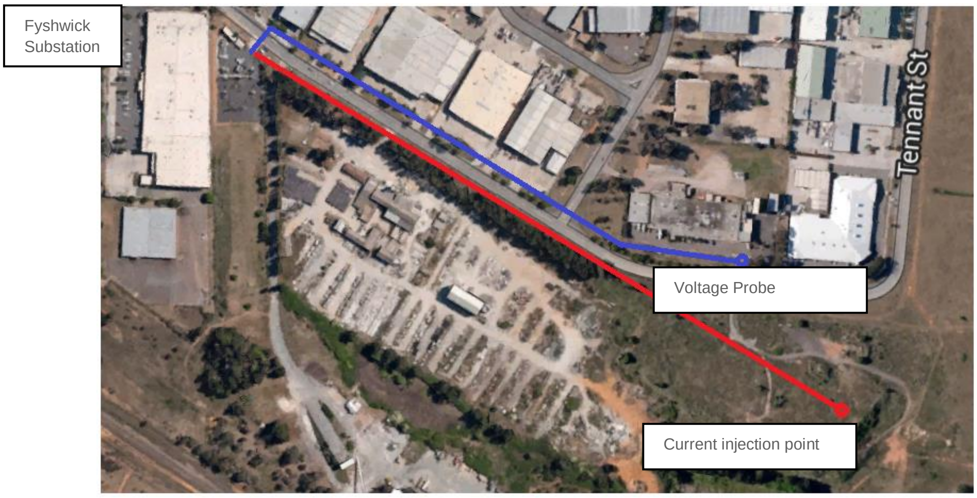


Figure 17 – Remote Earth or Test Current Electrodes

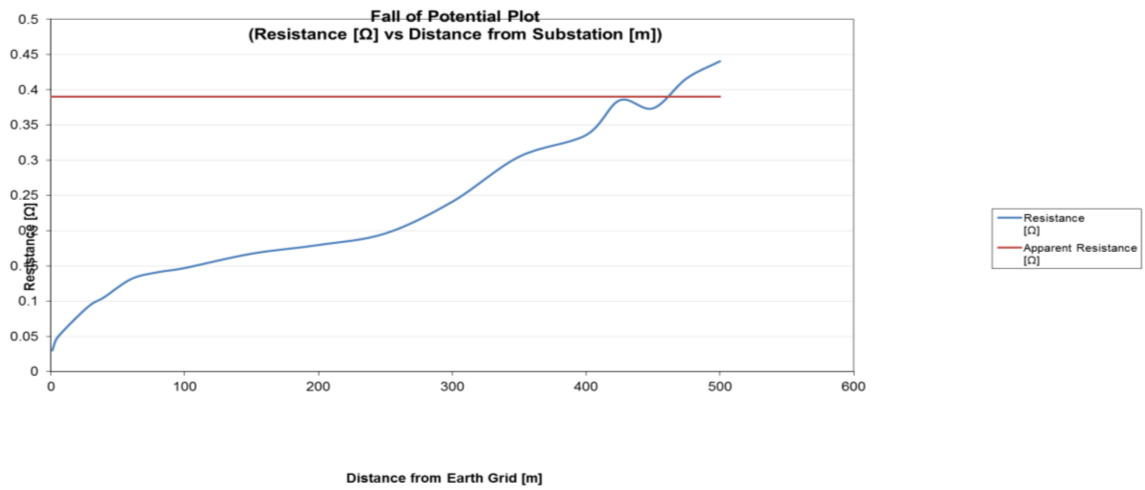
It was a sunny day when the remote earth was setup. The measured earth resistance using the Megger was 39.2 Ω.

8.2. Fall-of-Potential Plot

The measured voltages on the remote potential electrodes, when a six (6.13) Ampere current was injected into the earth test link at Fyshwick ZS, are detailed in Appendix A. The graphical summary is shown in Figure 18.

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 18 –Fyshwick ZS Earthing Fall-of-Potential Plot



It is preferred that the remote potential electrodes are run perpendicular to the current probes. This limits the likely influences mutual coupling or other interference. Due to the limitation of open areas around the Fyshwick ZS the potential electrodes was run parallel to the current electrodes. This has some effect on the fall of potential curve.

From Figure 18 –Fyshwick ZS Earthing Fall-of-Potential Plot, it is clear that there is some interference measured and is most evident in the slope between the 300m and 500m points.

However PSD uses a number of numerical methods (slope methods) of estimating the apparent resistance and expect the derived grid resistance to be with in the acceptable tolerances.

From the test results the apparent grid resistance equals 0.39Ω, 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	0.39	86.35	0.45

There are a marked difference between the modelled grid resistance in CDEGS 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 Fyshwick ZS and surroundings, the calculated EPR IS 3.35 kV.

`	Apparent Resistance [Ω]	Calculated Ig Ground Current (kA)	EPR [kV]
Earth Grid	0.39	8.58	3.35

(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.

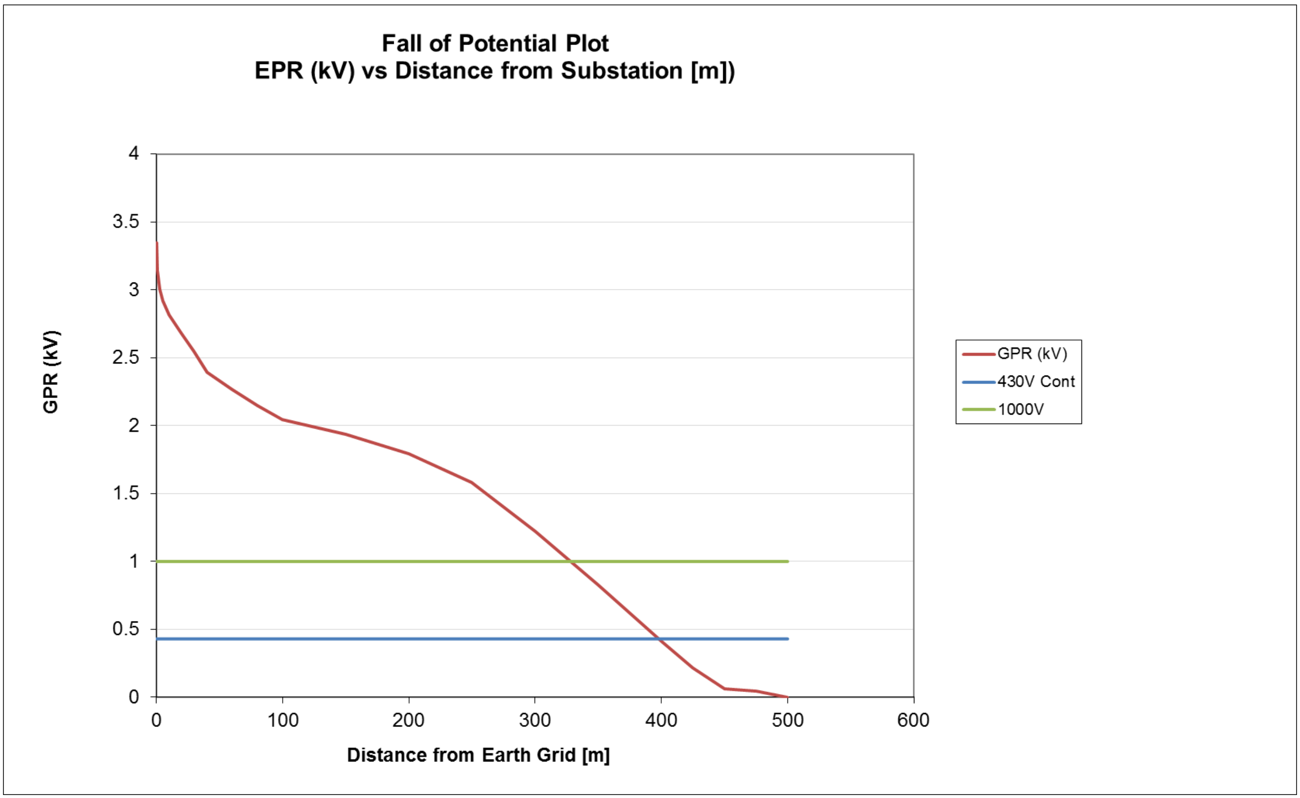
As the measured EPR exceeds the allowable step and touch voltage limits for 70 kg person tabulated in Table 5. Current injection test together with step and touch voltage measurements were required to verify if the existing earthing installation will not present a risk to the public.

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 1000V EPR contour measured extends approximately 300m outside the substation fence. Based on the calculated values and the interference evident from the measured curve it is considered that the calculated value in 7.7.2 - Telecommunication hot zone should be adhered to.

The 430V EPR contour extends approximately 400m outside the substation fence. Based on the calculated values and the interference evident from the measured curve it is considered that the calculated value in 7.7.2 - Telecommunication hot zone should be adhered to.



10. Step and Touch Voltage Measurement

Using the same test current electrodes or remote earth, the earth fault scenario at Fyshwick ZS and surroundings was simulated by injecting six (6.13) 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 19.

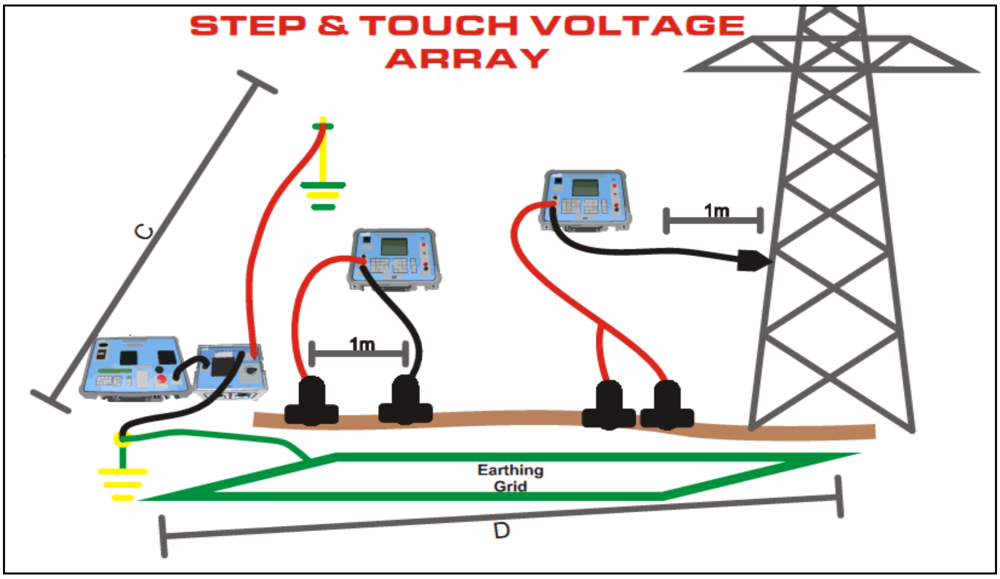


Figure 19 – Step & Touch Voltage Measurement Typical Setup

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

10.1. Step Voltage Measurement

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

All measurements were scaled using the maximum 11kV 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 Fyshwick 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:		**Fyshwick ZSS**	**Drawing Ref:**		**2209-6001**		
Test Equipment:		**Frequency Voltmeter**	**Serial Numbers/ Calibration Dates:**				
6.14	**A current injection**	**7.41**	**kA Fault level**		**1206.66**	**Scaling Factor**	
Weather/Soil Conditions:							
		Sunny /	**Cloudy**	**/**	**Raining**		
		Dry Soil /	**Moist Soil**	**/**	**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	Gate	NG	PA	4.45	5.37	193.58	PASS
2	PA Gate	NG	PA	25.75	31.07	193.58	PASS
3	Fence	NG	PA	16.76	20.22	193.58	PASS
4	Fence	NG	PA	12.4	14.96	193.58	PASS
5	Stairs	NG	PA	6.54	7.89	193.58	PASS
6	Stairs	NG	PA	5.8	7.00	193.58	PASS
7	Stairs	NG	PA	6.94	8.37	193.58	PASS
8	Fence	NG	PA	6.71	8.10	193.58	PASS
9	Fence	NG	PA	6.61	7.98	193.58	PASS
10	Gate	NG	PA	21.8	26.31	193.58	PASS
11	Gate	NG	PA	2	2.41	193.58	PASS
12a	Fence	NG	PA	2.21	2.67	193.58	PASS
12b	Neighbour Fence	NG	PA	42	50.68	193.58	PASS
12c	Pole	NG	PA	74.7	90.14	193.58	PASS
13	Not used	-	-	-	-	-	-
14	Control Building	CR	RA	1.55	1.87	2,838.32	PASS

Test #	Description of Test Point	Surface Type	Location Type	Measured Step Voltage Open Circuit (mV)	Scaled Value (V)	Safety Limits (V)	PASS /FAIL
15	Control Building	CR	RA	0.01	0.01	2,838.32	PASS
16	Control Building	CR	RA	0.42	0.51	2,838.32	PASS
17	Control Building Stairs	CR	RA	0.84	1.01	2,838.32	PASS
18	Control Building Stairs	CR	RA	12.23	14.76	2,838.32	PASS
19	Light Pole	CR	RA	0.023	0.03	2,838.32	PASS
20	Shed	CR	RA	0.18	0.22	2,838.32	PASS
21	Transformer 2	CR	RA	0.31	0.37	2,838.32	PASS
22	Busbar Support	CR	RA	13	15.69	2,838.32	PASS
23	Circuit Breaker and Current Transformer	CR	RA	21.1	25.46	2,838.32	PASS
24	High Level Busbar Support	CR	RA	3.5	4.22	2,838.32	PASS
25	Busbar Support	CR	RA	1	1.21	2,838.32	PASS
26	Busbar Support	CR	RA	3	3.62	2,838.32	PASS
27	Circuit Breaker and Current Transformer	CR	RA	30	36.20	2,838.32	PASS
28	Low Level Disconnector	CR	RA	4.9	5.91	2,838.32	PASS
29	Single Busbar Support	CR	RA	4.5	5.43	2,838.32	PASS
30	3 Phase Busbar Support	CR	RA	4	4.83	2,838.32	PASS
31	Single Busbar Support	CR	RA	4	4.83	2,838.32	PASS
32	Single Busbar Support	CR	RA	4.7	5.67	2,838.32	PASS
33	3 Phase Busbar Support	CR	RA	3.5	4.22	2,838.32	PASS
34	Single Busbar Support	CR	RA	4.3	5.19	2,838.32	PASS

Test #	Description of Test Point	Surface Type	Location Type	Measured Step Voltage Open Circuit (mV)	Scaled Value (V)	Safety Limits (V)	PASS /FAIL
35	Low Level Disconnector	CR	RA	5.7	6.88	2,838.32	PASS
36	Circuit Breaker and Current Transformer	CR	RA	8	9.65	2,838.32	PASS
37	3 Phase Busbar Support	CR	RA	6.3	7.60	2,838.32	PASS
38	Single Busbar Support	CR	RA	3.7	4.46	2,838.32	PASS
39	3 Phase Busbar Support	CR	RA	2.1	2.53	2,838.32	PASS
40	Low Level Disconnector	CR	RA	1	1.21	2,838.32	PASS
41	Low Level Disconnector	CR	RA	1	1.21	2,838.32	PASS
42	Low Level Disconnector	CR	RA	2.8	3.38	2,838.32	PASS
43	Circuit Breaker and Current Transformer	CR	RA	20	24.13	2,838.32	PASS
44	Busbar Support	CR	RA	4.7	5.67	2,838.32	PASS
45	Strain Structure	CR	RA	2.2	2.65	2,838.32	PASS
46	Strain Structure	CR	RA	2.2	2.65	2,838.32	PASS
47	Strain Structure	CR	RA	2.93	3.54	2,838.32	PASS
48	Strain Structure	CR	RA	2.93	3.54	2,838.32	PASS
49	Strain Structure	CR	RA	2.93	3.54	2,838.32	PASS
50	Circuit Breaker and Current Transformer	CR	RA	10	12.07	2,838.32	PASS
51	Busbar Support	CR	RA	27	32.58	2,838.32	PASS
52	Transformer 1	CR	RA	3.9	4.71	2,838.32	PASS
53	Transformer 1	CR	RA	1.5	1.81	2,838.32	PASS

10.2. Touch Voltage Measurement

There were unsafe touch voltages measured in Fyshwick ZS and surroundings.

Table 9 details the test points where the excessive touch potentials were measured.

Table 9 - Excessive Touch Potential Measured

Test #	Description of Test Point	PASS /FAIL
3	Fence North Western Corner	FAIL
4	Fence North Western Corner	FAIL
8	Fence South Western Corner	FAIL
12b	Neighbour Fence South Eastern 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
3	Fence	AS	PA	142.2	171.58707	1058.1838	PASS
4	Fence	AS	PA	145.3	175.32771	1058.1838	PASS
8	Fence	AS	PA	198	238.9187	1058.1838	PASS
12b	Neighbour Fence	AS	PA	144.6	174.48305	1058.1838	PASS

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

All measurements were scaled using the maximum 11kV 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 Fyshwick 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:	**Fyshwick ZSS**		**Drawing Ref:**		**2209-6001**		
Test Equipment:	**Frequency Voltmeter**		**Serial Numbers:**		Calibration Dates:		
6.14	**A current injection**	**7.41**	**kA Fault level**		**1206.66**	**Scaling Factor**	
Weather/Soil Conditions:							
		Sunny / Dry Soil /		**Cloudy / Moist Soil /**		**Raining / Saturated Soil**	
Test #	**Description of Test Point**	**Surface Type**	**Location Type**	**Measured Touch Voltage Open Circuit (mV)**	**Scaled Value (V)**	**Safety Limits (V)**	**PASS /FAIL**
1	Gate	NG	PA	7.26	8.76	171.43	PASS
2	PA Gate	NG	PA	57	68.78	171.43	PASS
3	Fence	NG	PA	142.2	171.59	171.43	FAIL
4	Fence	NG	PA	145.3	175.33	171.43	FAIL
5	Stairs	NG	PA	17.7	21.36	171.43	PASS
6	Stairs	NG	PA	23.15	27.93	171.43	PASS
7	Stairs	NG	PA	141	170.14	171.43	PASS
8	Fence	NG	PA	198	238.92	171.43	FAIL
9	Fence	NG	PA	11	13.27	171.43	PASS
10	Gate	NG	PA	50.4	60.82	171.43	PASS
11	Gate	NG	PA	32	38.61	171.43	PASS
12a	Fence	NG	PA	59	71.19	171.43	PASS
12b	Neighbour Fence	NG	PA	144.6	174.48	171.43	FAIL
12c	Pole	NG	PA	101.7	122.72	171.43	PASS
13							
14	Control Building	CR	RA	55	66.37	876.10	PASS
15	Control Building	CR	RA	1.9	2.29	876.10	PASS
16	Control Building	CR	RA	28.5	34.39	876.10	PASS

Test #	Description of Test Point	Surface Type	Location Type	Measured Touch Voltage Open Circuit (mV)	Scaled Value (V)	Safety Limits (V)	PASS /FAIL
17	Control Building Stairs	CR	RA	21.49	25.93	876.10	PASS
18	Control Building Stairs	CR	RA	55.8	67.33	876.10	PASS
19	Light Pole	CR	RA	14.03	16.93	876.10	PASS
20	Shed	CR	RA	15.6	18.82	876.10	PASS
21	Transformer 2	CR	RA	0.8	0.97	876.10	PASS
22	Busbar Support	CR	RA	1.3	1.57	876.10	PASS
23	Circuit Breaker and Current Transformer	CR	RA	1	1.21	876.10	PASS
24	High Level Busbar Support	CR	RA	9	10.86	876.10	PASS
25	Busbar Support	CR	RA	1	1.21	876.10	PASS
26	Busbar Support	CR	RA	13	15.69	876.10	PASS
27	Circuit Breaker and Current Transformer	CR	RA	4	4.83	876.10	PASS
28	Low Level Disconnector	CR	RA	13	15.69	876.10	PASS
29	Single Busbar Support	CR	RA	3.5	4.22	876.10	PASS
30	3 Phase Busbar Support	CR	RA	4.7	5.67	876.10	PASS
31	Single Busbar Support	CR	RA	3	3.62	876.10	PASS
32	Single Busbar Support	CR	RA	4	4.83	876.10	PASS
33	3 Phase Busbar Support	CR	RA	3.2	3.86	876.10	PASS
34	Single Busbar Support	CR	RA	7.8	9.41	876.10	PASS
35	Low Level Disconnector	CR	RA	3.4	4.10	876.10	PASS
36	Circuit Breaker and Current Transformer	CR	RA	2	2.41	876.10	PASS
37	3 Phase Busbar Support	CR	RA	54	65.16	876.10	PASS

Test #	Description of Test Point	Surface Type	Location Type	Measured Touch Voltage Open Circuit (mV)	Scaled Value (V)	Safety Limits (V)	PASS /FAIL
38	Single Busbar Support	CR	RA	2.9	3.50	876.10	PASS
39	3 Phase Busbar Support	CR	RA	2.1	2.53	876.10	PASS
40	Low Level Disconnector	CR	RA	2	2.41	876.10	PASS
41	Low Level Disconnector	CR	RA	1	1.21	876.10	PASS
42	Low Level Disconnector	CR	RA	14	16.89	876.10	PASS
43	Circuit Breaker and Current Transformer	CR	RA	2	2.41	876.10	PASS
44	Busbar Support	CR	RA	0	0.00	876.10	PASS
45	Strain Structure	CR	RA	3.4	4.10	876.10	PASS
46	Strain Structure	CR	RA	5	6.03	876.10	PASS
47	Strain Structure	CR	RA	11.7	14.12	876.10	PASS
48	Strain Structure	CR	RA	20.1	24.25	876.10	PASS
49	Strain Structure	CR	RA	28.4	34.27	876.10	PASS
50	Circuit Breaker and Current Transformer	CR	RA	51	61.54	876.10	PASS
51	Busbar Support	CR	RA	20	24.13	876.10	PASS
52	Transformer 1	CR	RA	54	65.16	876.10	PASS
53	Transformer 1	CR	RA	1.6	1.93	876.10	PASS

10.3. Reach Touch Voltage Measurement

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

☝ Reach touch potentials were measured between the substation boundary fence and

neighbouring fencing as well as the steel stairs leading to the neighbouring building. Although the fencing and the stairs are outside the distance required for reach touch potentials, there are the potential to have voltages above the required safety limits at these points. No action is required at this point, however this needs to be considered in future expansion or fencing upgrades.

All measurements were scaled using the maximum 11kV 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.

Table 12 - Reach Touch Measurements

Test #	Description of Test Point	Surface Type	Location Type	Measured Touch Voltage Open Circuit (mV)	Scaled Value (V)	Safety Limits (V)	PASS /FAIL
5	Stairs	HL	PA	122.7	148.06	164.05	PASS
6	Stairs	HL	PA	132	159.28	164.05	PASS
7	Stairs	HL	PA	143	172.55	164.05	FAIL
12b	Neighbour Fence	HL	PA	400	482.66	164.05	FAIL

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

10.4. Metallic Pipelines in the Vicinity

There are no visible and/or above ground metallic pipelines in close proximity of Fyshwick 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 Fyshwick 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 Fyshwick 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 13 - Substation Earth Grid Continuity. The mapped locations for the Substation Earth Grid Continuity are shown in 14.Appendix D

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. Most of the structure within the substation is painted and some of the connections seem to be onto the painted surface only.

- It is also noted that the earthing connection from the overhead earth wire on the overhead line terminal poles coming into the substation is not adequately bonded to the substation earth grid. The overhead earth wires needs to have a dedicated earth connection to the substation earth grid. This will require remedial action.

Table 13 - 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:	**Fyshwick ZSS**	**Drawing Ref:**	**2209-6301**
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
0	Cable Test lead	0	PASS	
1	Circuit Breaker Structure Earth	0.01	PASS	
2	Circuit Breaker and Current Transformer Operators Earth Mat	0.01	PASS	
3	Current Transformer Structure Earth	0.01	PASS	
4	Disconnector Structure Earth	0	PASS	
5	Disconnector Structure Earth	0.01	PASS	
6	Disconnector Structure Earth	0.01	PASS	
7	OH Conductor Gantry Pole Earth	3.02	FAIL	
8	OH Conductor Gantry Pole Earth	0.033	FAIL	
9	Disconnector Structure Earth	0.01	PASS	
10	Disconnector Structure Earth	0.01	PASS	
11	3 Phase Busbar Support Earth	0.01	PASS	
12	Single Busbar Support Earth	0.01	PASS	
13	Single Busbar Support Earth	0.01	PASS	
14	Single Busbar Support Earth	0.01	PASS	
15	3 Phase Busbar Support Earth	0.01	PASS	
16	Circuit Breaker and Current Transformer Structure	0.01	PASS	
17	3 Phase Busbar Support	0.01	PASS	
18	Transformer 2 Tanks	0.01	PASS	
19	Circuit Breaker and Current Transformer Structure	0.01	PASS	

Weather/Soil Conditions:	**Sunny / Cloudy / Raining** **Dry Soil / Moist Soil / Saturated Soil**

20	Disconnector Structure	0.02	FAIL	
21	Disconnector Operators Earth Mat	0.01	PASS	
22	Circuit Breaker and Current Transformer Operators Earth Mat	0.01	PASS	
23	Single Busbar Support Earth	0.02	FAIL	
24	Single Busbar Support Earth	0.01	PASS	
25	Single Busbar Support Earth	0.01	PASS	
26	3 Phase Busbar Support	0.02	FAIL	
27	Single Busbar Support Earth	0.04	FAIL	
28	Single Busbar Support Earth	0.01	PASS	
29	OH Line Gantry Pole Earth	0.05	FAIL	
30	OH Line Gantry Pole Earth	0.01	PASS	
31	Single Busbar Support Earth	0.01	PASS	
32	Single Busbar Support Earth	0.01	PASS	
33	3 Phase Busbar Support	0.01	PASS	
34	OH Line Gantry Pole Earth	0.014	FAIL	
35	OH Line Gantry Pole Earth	0.02	FAIL	
36	NA	-	-	
37	Single Busbar Support	0.01	PASS	
38	Single Busbar Support	0.01	PASS	
39	Single Busbar Support	0.01	PASS	
40	Disconnector Operators Earth Mat	0.01	PASS	
41	Disconnector Operators Earth Mat	0.01	PASS	
42	Disconnector Structure	0.014	FAIL	
43	Disconnector Operators Earth Mat	0.03	FAIL	
44	3 Phase Busbar Support	0.01	PASS	
45	Single Busbar Support	0.01	PASS	
46	Single Busbar Support	0.01	PASS	
47	Single Busbar Support	0.014	FAIL	
48	3 Phase Busbar Support	0.01	PASS	
49	Circuit Breaker and Current Transformer Structure	0.02	FAIL	
50	Circuit Breaker and Current Transformer Operators Earth Mat	0.014	FAIL	
51	Disconnector Structure	0.01	PASS	
52	Disconnector Operators Earth Mat	0.01	PASS	
53	Transformer 3 Tanks	0.01	PASS	

Weather/Soil Conditions:	Sunny / Cloudy / Raining Dry Soil / Moist Soil / Saturated Soil			
54	Circuit Breaker and Current Transformer Structure	0.01	PASS	
55	Circuit Breaker and Current Transformer Operators Earth Mat	0.44	FAIL	
56	3 Phase Busbar Support	0.01	PASS	
57	Transformer 1 Tanks	0.02	FAIL	
58	Lighting Mast	0.37	FAIL	
59	Station Transformer	0.012	FAIL	
60	Station Transformer	0.014	FAIL	
61	Building Steps	0.01	PASS	
62	Building Steps	0.09	FAIL	
63	Control Building Plug Box	0.68	FAIL	
64	Gate Post	0.01	PASS	
65	Gate Post	0.025	FAIL	

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 14 - Earth grid conductor sizing

Table 14 - 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	6.01	3	48.15
Risers	8.58	3	113.27

As per drawings 2209-6301 main grid installed consist of 37/2.37 hard drawn stranded bare copper earthing conductors laid in the ground. All high voltage equipment and transformer tanks are connected to the main earth grid using 38x3mm hard drawn copper strap earthing.

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

The main grid conductor effectively has a cross sectional area of $147mm^2$, and is adequately sized for the fault current. There is also adequate margined if the fault level increases in future.

☝ The main grid conductor effectively has a cross sectional area of $114mm^2$, and is

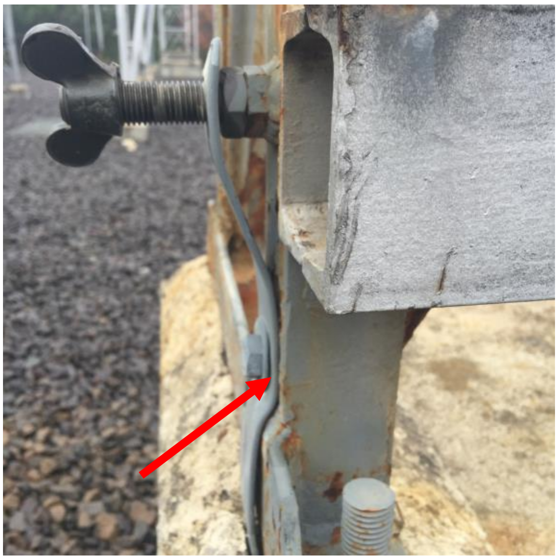
adequately sized for the current fault current. However there is no margined if the fault level increases in future.

13. Visual inspection and observations

Visual Inspection Notes	**Photos**
On the 66kV Queanbey Line 844 & 845 the earthing connection from the overhead earth wire on the overhead line terminal poles coming into the substation is not adequately bonded to the substation earth grid. The overhead earth wire needs to have a dedicated earth connection to the substation earth grid. It is advised that a dedicated $120mm^2$ conductor is installed at each overhead gantry pole connected from the OHEW to the earth grid.	

Visual Inspection Notes	Photos
The above mentioned problems also exist on the overhead gantry next to the transformers. The overhead earth wire needs to have a dedicated earth connection to the substation earth grid. It is advised that a dedicated 120mm^2 conductor is installed at each overhead gantry pole connected from the OHEW to the 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 and the earth grid does not have a grading ring for the gate opening outwards. This presents a safety risk and it is advised that the gates are fitted with a stopper to prevent them from opening outwards, alternatively a grading ring is to be installed covering the full swing of the gate	

Visual Inspection Notes	Photos
The earth grid was exposed and the earth grid conductor and riser sizing confirmed against the substation drawings. It is also noted that the yard stone is in excess of 100mm thick and in a healthy condition.	
Reach touch potentials were measured between the substation boundary fence and neighbouring fencing as well as the steel stairs leading to the neighbouring building. Although the fencing and the stairs are outside the distance required for reach touch potentials, there are reach potential to have voltages above the required safety limits at these points. No action is required at this point, however this needs to be considered in future expansion or fencing upgrades	

Visual Inspection Notes	Photos
Reach touch potentials were measured between the substation boundary fence and neighbouring fencing as well as the steel stairs leading to the neighbouring building. Although the fencing and the stairs are outside the distance required for reach touch potentials, there are reach potentials having voltages above the required safety limits at these points. No action is required at this point, however this needs to be considered in future expansion or fencing upgrades	
Most 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.	

Visual Inspection Notes	Photos
The control room building Structure earthing is inadequate. All steel part should be bonded, doors to have a flexible bonding strap and to be earthed to the grid at a minimum of two points.	
The Fence is earthed in accordance with the drawings and the industry standards at every second post.	

Visual Inspection Notes	**Photos**
It was observed that there were infrastructures installed in the substation that are not recorded on the drawings. These include two of auxiliary transformer and the 11kV switch room.	

14. Conclusion

This report details the result of the earthing test conducted by PSD Energy at Fyshwick 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 uses 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.

Visual Inspection:

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

It was observed that there were infrastructures installed in the substation that were not recorded on the drawings. These include two of auxiliary transformer and the 11kV switch room.

The fence is earthed in accordance with the industry standards at every second fence post with a 38x3mm copper flat strap as per the drawings. The primary plant is earthed in accordance with the drawings via a 38x3mm 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.

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 and the earth grid does not have a grading ring for the gate opening outwards. This presents a safety risk.

It is also noted that the earthing connection from the overhead earth wire on the overhead line terminal poles coming into the substation is not adequately bonded to the substation earth grid. The overhead earth wires needs to have a dedicated earth connection to the substation earth grid. This will require remedial action.

Step and Touch Potentials:

There are good convergence between the modelled step and touch potentials and the actual measured values. Both modelling and site measurement revealed there are high risk of touch voltages along the outside fence line**.**

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 at the south eastern stern corner. The substation boundary fence is close to the neighbouring fence and high touch voltages were measured at this point.

Reach touch potentials were measured between the substation boundary fence and neighbouring fencing as well as the steel stairs leading to the neighbouring building. Although the fencing and the stairs are outside the distance required for reach touch potentials, there are reach potentials having voltages above the required safety limits at these points. No action is required at this point, however this needs to be considered in the future expansion or fencing upgrades.

Equipment Bonding:

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.

Most 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.

Conductor Sizing:

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

The main grid conductor effectively has a cross sectional area of $147mm^2$, and is adequately sized for the fault current. There is also adequate margined if the fault level increases in future.

☝ The main grid riser effectively has a cross sectional area of 114mm^2, and is

adequately sized for the current fault current. However there is no margined if the fault level increases in future.

Recommendations

1. Gantries & Overhead Earth wire: It is advised that a dedicated 120mm^2 conductor is installed at each overhead gantry pole (total of 8 – items 1,2,3,4 & 7,8,9,10 as per 14.Appendix B) connected from the OHEW to the earth grid.
2. Substation Fence External: It is advised that 1.5 wide 30mm thick layer of asphalt is placed around the outside of the substation, in order to mitigate the potential high touch voltages.
3. Substation Fence Gates: It is advised that the gates are fitted with a stopper to prevent it from opening outwards. Alternatively, a grading ring can be installed covering the full swing of the gate.
4. Control Room: The control room building Structure earthing is inadequate. All steel part should be bonded, doors to have a flexible bonding strap and to be earthed to the grid at a minimum of two points.
5. 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 11 kV 8.58 kA earth fault current with fault clearing time of 0.5 second.

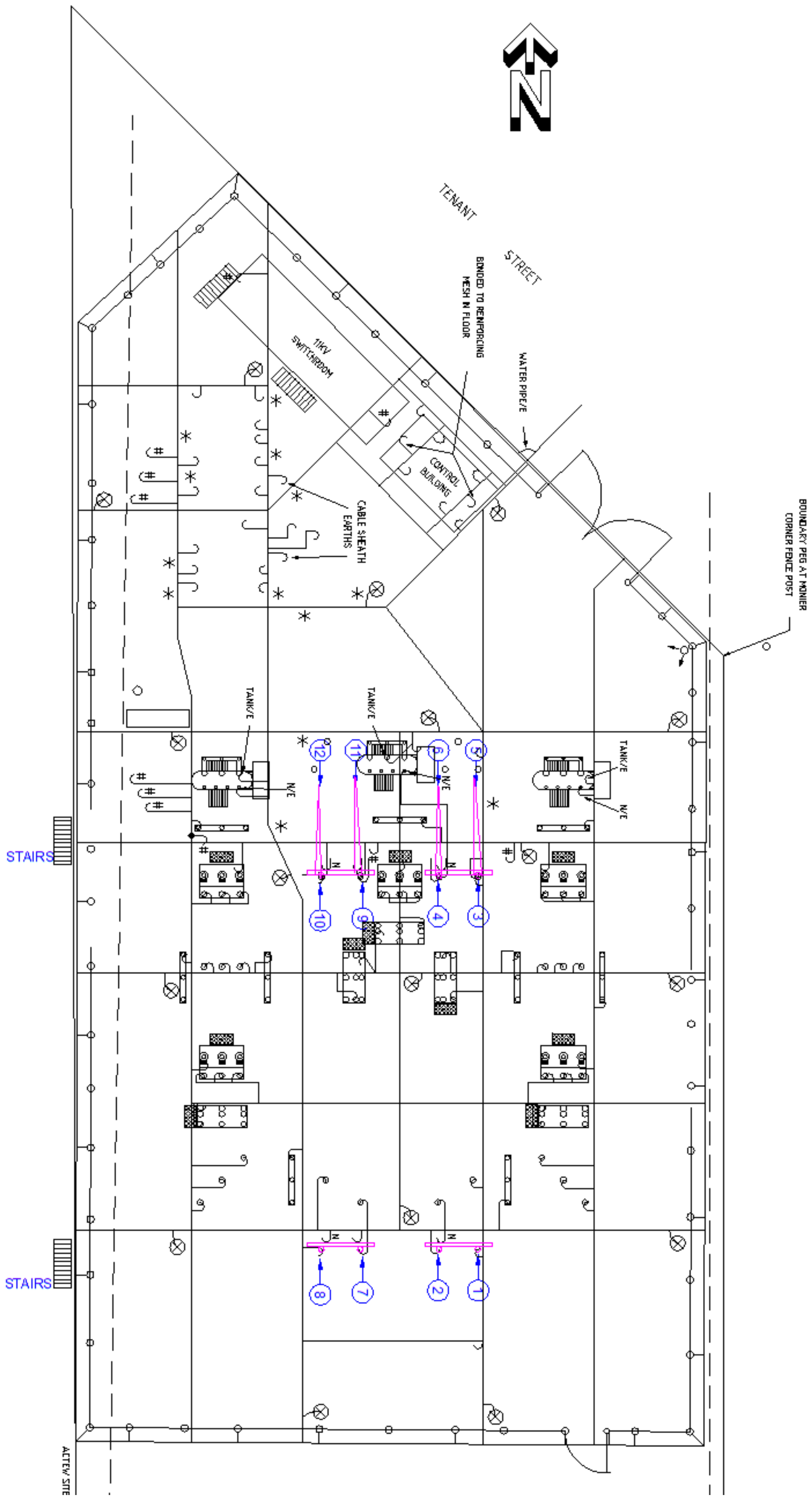
Appendix A Fall-of-Potential Test Result

Date:	**14/01/2015**	**Site Supervisor:**	**T Strydom**
Project No:	**PSD0783**	**Carried Out By:**	**C Pretorius**
Project Desc:	**Substation Earth Testing**		
Site Location:	**Fyshwick ZSS**		
Test Equipment:	**Red Phase**	**Serial Numbers:**	
Current Injected:	**6.13**	**Calibration Date:**	
Weather/Soil Conditions:	**Sunny / Cloudy / Raining** **Dry Soil / Moist Soil / Saturated Soil**		

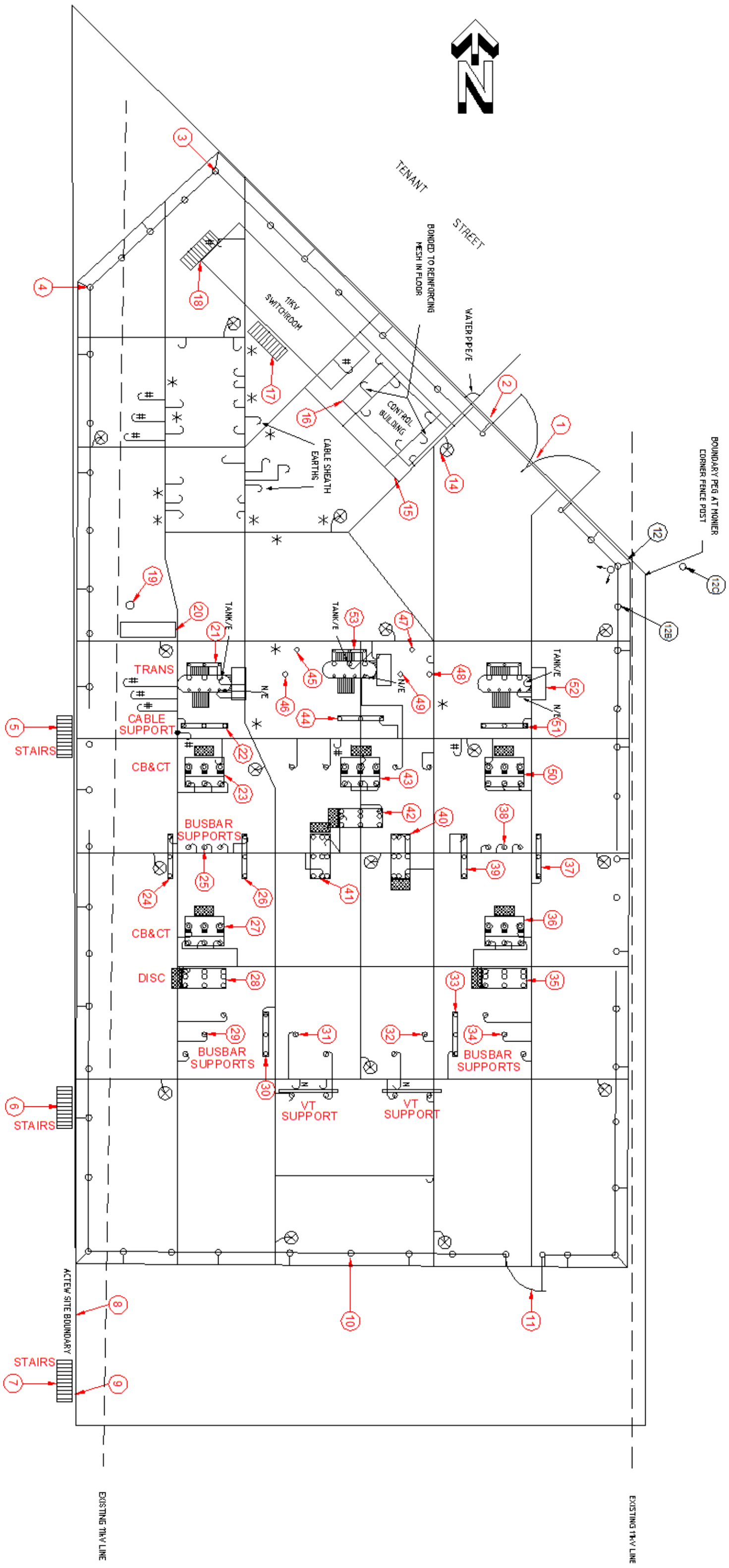
Distance From Grid (m)	**Measured Voltage (V)**	**Resistance [Ω]**
0	0	0
1	0.184	0.030016313
3	0.258	0.042088091
5	0.299	0.048776509
10	0.364	0.059380098
20	0.481	0.078466558
30	0.585	0.0954323
40	0.649	0.105872757
60	0.806	0.131484502
80	0.865	0.141109299
100	0.901	0.146982055
150	1.026	0.167373573
200	1.101	0.179608483
250	1.202	0.196084829
300	1.478	0.241109299
350	1.87	0.305057096
400	2.058	0.335725938
425	2.36	0.384991843
450	2.29	0.373572594
475	2.55	0.415986949
500	2.7	0.44045677

Appendix B Fault Current Distribution

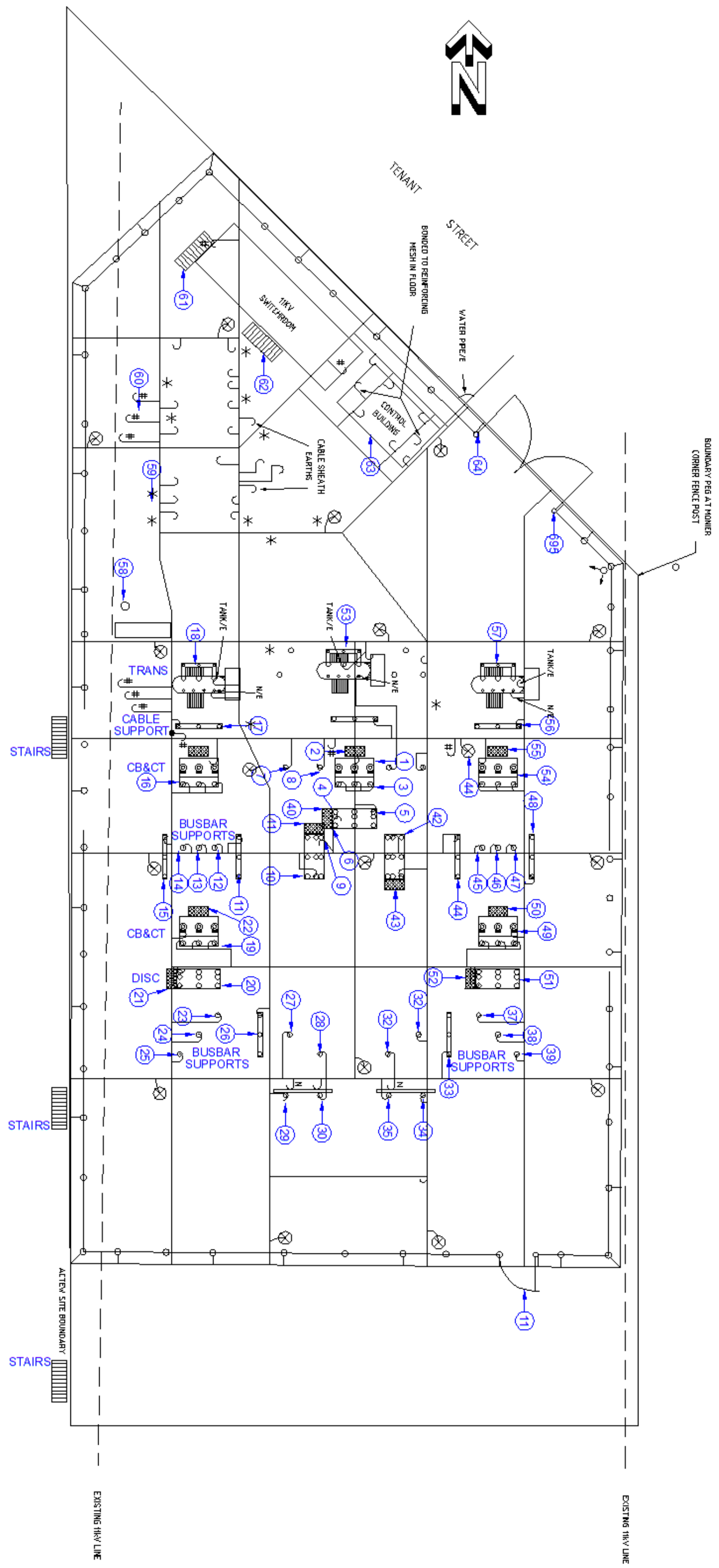
Current Distribution Measurements				
Point	**Location**	**Measured Current**	**Injected value**	**% Split**
Total	**66kV OHEW**	**0.8367**	**6.13**	**13.65**
1	0844 Quenanbeyan Line Landing Gantry East Pole	0.0012	6.13	0.02
2	844 Quenanbeyan Line Landing Gantry West Pole	0.144	6.13	2.35
3	844 Quenanbeyan Line Transf Gantry East Pole	0	6.13	0.00
4	844 Quenanbeyan Line Transf Gantry West Pole	0	6.13	0.00
5	844 Quenanbeyan Line Transf Gantry East Pole Stay	0.2	6.13	3.26
6	844 Quenanbeyan Line Transf Gantry West Pole Stay	0	6.13	0.00
7	0845 Quenanbeyan Line Landing Gantry East Pole	0.147	6.13	2.40
8	845 Quenanbeyan Line Landing Gantry West Pole	0.206	6.13	3.36
9	845 Quenanbeyan Line Transf Gantry East Pole	0.001	6.13	0.02
10	845 Quenanbeyan Line Transf Gantry West Pole	0.1275	6.13	2.08
11	845 Quenanbeyan Line Transf Gantry East Pole Stay	0	6.13	0.00
12	845 Quenanbeyan Line Transf Gantry West Pole Stay	0.01	6.13	0.16


N
TENANT STREET
BONDED TO REINFORCING MESH IN FLOOR
WATER PIPE/E
11KV SWITCHROOM
CONTROL BUILDING
CABLE SHEATH EARTHS
BOUNDARY PEG AT MONIER CORNER FENCE POST
TANK/E
N/E
STAIRS
STAIRS
ACTEW SITE
1
2
3
4
5
6
7
8
9
10
11
12

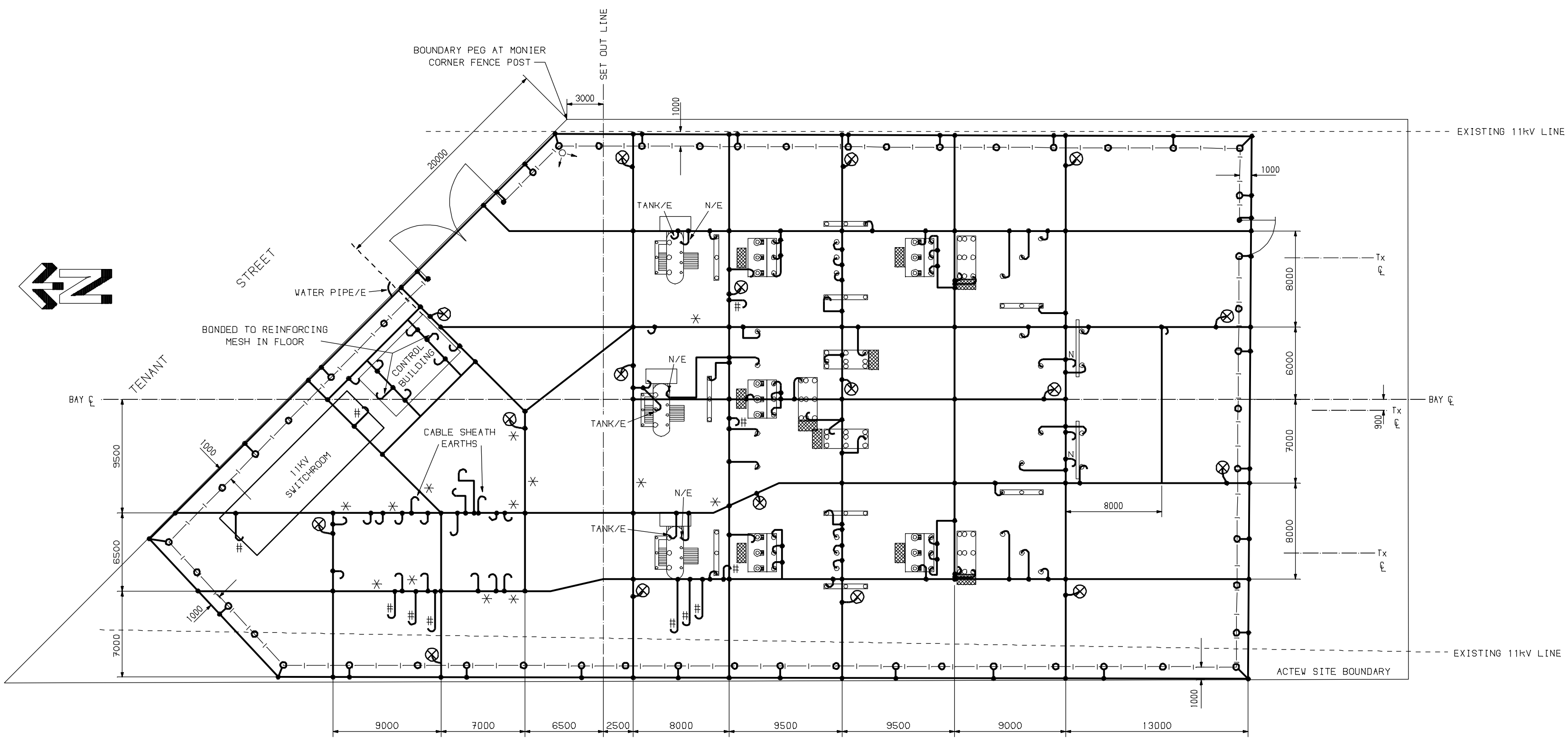
Appendix C Step and Touch Voltage Test Locations



Appendix D Grid Continuity Test Locations



Appendix E 66/11 kV Fyshwick ZS Earthing Arrangement



LEGEND:

⊗	EARTH ELECTRODE 3m LONG 37/2.25 COPPER
—	EARTH GRID 37/2.25 COPPER BURIED 750 DEEP
╯	EARTH TAIL 38 × 3 COPPER TO EQUIPMENT
▩	EARTH MAT
N/E	150mm COPPER CABLE 37/2.25 PVC INSULATED BLACK VIA C.T.
N	NEUTRAL CONNECTION
*	BURY 1200 DEEP WHERE CABLES ARE LAID
#	NEW EARTH TAILS FOR NEW 11KV SWITCHROOM & CABLE CULVERTS

NOTE:

1. THIS DRAWING SUPERSEDES 2209-6200.

No.	Description	Date	Init	No.	Description	Date	Init
C	EARTH TAILS ADDED	5/00					
B	REDRAWN	4/00					

AMENDMENTS

WORK AS EXECUTED

-----------------/--/--

Drawn *ADD*
Checked
Design Authority

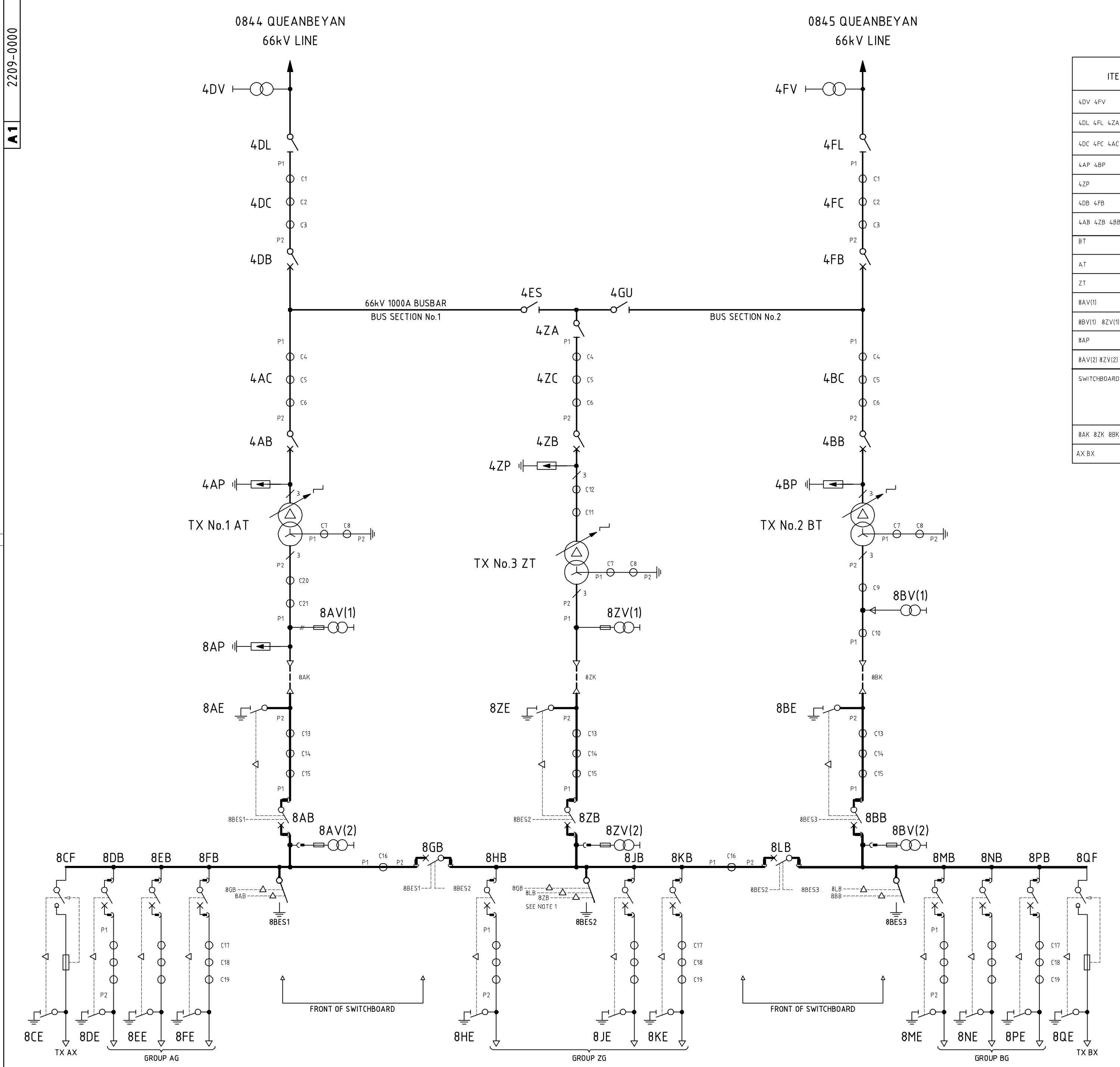
ACTEW CORPORATION

FYSHWICK 66/11kV ZONE SUBSTATION
EARTHING ARRANGEMENT

Scale 1:200	Date 28/04/2000	Sheet No.
File	Tender No.	
CADD FILE Name FY6301.FGB		Amdmt.
2209-6301		C

A1

Appendix F Fyshwick 66 kV ZS Single Line Diagram



No	REVISION	DATE	CKD	AUTH
M	AS CONTRUSTED	5/2/08	D G.	
N	TRANSFORMER No.3 REPLACED & ISSUED FOR CONSTRUCTION	5/7/13		
O	C12 ADDED, WAE	19/7/13	D.G.	F.G.
P	Tx2 CT LOCATION CORRECTED	21/3/14	RM	JC

ITEM IDENT.	DESCRIPTION	QTY	MAKE	TENDER No.
4DV 4FV	66,000V 3 PHASE VOLTAGE TX 200VA CLASS 0.5	2	ENDURANCE ELECTRIC	
4DL 4FL 4ZA 4ES 4GU	66,000V 600A VSB ISOLATOR	5	A.L.M.	CESE474
4DC 4FC 4AC 4BC 4ZC	66,000V CURRENT TRANSFORMER TYPE 1MBA 70-A3-600A	5	ABB	E1627
4AP 4BP	66,000V LIGHTNING ARRESTORS TYPE PEXLIM R060 - YV072	6	ABB	
4ZP	66,000V LIGHTNING ARRESTORS TYPE PEXLIM R066 - CV072	3	ABB	284701
4DB 4FB	66,000V CIRCUIT BREAKER TYPE HKEYC 60/800A 2500MVA	2	ABB	
4AB 4ZB 4BB	66,000V CIRCUIT BREAKER TYPE HKEYC 60/800A 2000MVA	3	ABB	
BT	66kV/11kV TRANSFORMER 15-25 MVA ONAN OFAN	1	WILSON	867/07
AT	66kV/11kV TRANSFORMER 16-20 MVA ONAN ONAF	1	ABB	774/04
ZT	66kV/11kV TRANSFORMER 25 MVA ONAN	1	WILSON	284701
8AV(1)	VOLTAGE TRANSFORMER 11,000/110V CLASS 0.5 M 300VA THREE PHASE WITHIN MAIN TRANSFORMER TANK	1		
8BV(1) 8ZV(1)	VOLTAGE TRANSFORMER 11,000/110V CLASS 0.5 M 300VA THREE PHASE TRANSFORMER	2	CIRCLE -C	867/07
8AP	11,000V LIGHTNING ARRESTORS	6		
8AV(2) 8ZV(2) 8BV(2)	11000V/110V 100VA CL 0.5-1P 3 PHASE VOLTAGE TX	3	HAWKER SIDDELEY	568/99
SWITCHBOARD	12kV METAL CLAD SWITCHBOARD COMPLETE WITH 9 x 630A VCB's 5 x 2000A VCB's 38 x CT's THREE PHASE	1	HAWKER SIDDELEY	568/99
8AK 8ZK 8BK	11kV CABLES SINGLES 630mm² COPPER XLPE 12.7/22kV	2 PER Ø	PIRELLI	571/99
AX BX	11kV/433 AUXILIARY TRANSFORMER 100kVA Dyn1	2	AW TYREE	

IDENT.	CORE	CURRENT TRANSFORMER DESCRIPTION
AT	C21	LINE DROP COMPENSATION CT A, B & C PHASES OF TRANSFORMER LV SIDE 1200/5 30VA CLASS 1
	C20	W.T.I. CT B PHASE OF TRANSFORMER LV SIDE 850/2 15VA CLASS 1
FEEDERS 8DB - 8PB	C19	INSTRUMENTS 600/300/5 CL 0.5 15VA
	C18	OVERCURRENT/EARTH FAULT PROT. 600/300/5 10P50F20 AT 300/5
	C17	BACKUP PROTECTION 600/300/5 10P50F20 AT 300/5
8GB 8LB	C16	PROTECTION CLASS 1600/800/5 10P50F20
8AB 8BB 8ZB	C15	TRANSF. DIFF. PROT. 1300/1 10P300F20
	C14	INSTRUMENTS 1600/800/5 CLASS 0.5M 15VA
	C13	OVERCURRENT 1600/800/5 10P50F20
ZT	C11	400/1A 12.5VA CLASS 5P20 (SPARE)
	C11	W.T.I. CT B PHASE OF TRANSFORMER LV SIDE 300/2 15VA CLASS 5M
BT	C10	LINE DROP COMPENSATION CT A, B & C PHASES OF TRANSFORMER LV SIDE 1200/5 30VA CLASS 1
	C9	W.T.I. CT B PHASE OF TRANSFORMER LV SIDE 1350/2 CLASS 5M 15VA
AT BT ZT EARTH LEG	C8	RESTRICTED EARTH FAULT 1300/1 10P300F20
	C7	NEUTRAL EARTH FAULT PROTECTION 750/5 10P200
4AC 4BC 4ZC	C6	TRANSF. DIFF. PROT. 125/1 10P5250
	C5	66kV OVERCURRENT PROTECTION 500/250/5 10P100
	C4	INSTRUMENTS 600/300/5 30VA CLASS 0.5
4DC 4FC	C3	LINE DISTANCE PROTECTION 500/250/5 10P100
	C2	DIRECTIONAL EARTH FAULT PROTECTION 500/250/5 10P100
	C1	METERING 600/300/5 30VA CLASS AM

NOTES.

1. BUSBAR EARTHING SWITCH ON EACH BUS CAN ONLY BE CLOSED WHEN ASSOCIATED TRANSFORMER CB AND BUS SECTION CB ARE OPEN WITH MECHANISMS LOCKED.

ActewAGL

FYSHWICK 66kV ZONE SUBSTATION SINGLE LINE DIAGRAM

DRAWN:- DATE:- 6/3/01
DESIGN OFFICER:-
PROTECTION ENGINEER:-
BRANCH MANAGER:-

A1 2209-0000 REV P

A1 2209-0000