Earthing Design Instruction

Distribution earthing test

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51 Huntingwood Drive, Huntingwood NSW 2148

Postal address: PO Box 811 Seven Hills 1730

Phone: 131 318 **Fax**: (02) 9853 6000

EDI 0005 – Distribution earthing test

Comments and Enquiries

To enable Endeavour Energy to continually improve its standards and practices, feedback is encouraged. Any comments or suggestions shall be forwarded to:

earthingenquiry@endeavourenergy.com.au

or alternatively by mail to:

Primary Systems Engineering,

Huntingwood First Floor West,

C/O PO Box 811, Seven Hills 1730

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Amendment record

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EARTHING DESIGN INSTRUCTION

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EDI 0005 Distribution earthing test

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1.0 PURPOSE

The purpose of this document is to detail the requirements for the testing and inspection of distribution earthing systems on Endeavour Energy's network in order to ensure that designed risk outcomes and earthing integrity are maintained over the life of the asset. This documents aims for the testing for design, maintenance or commissioning purposes of distribution earthing systems on the network to be carried out in a consistent manner in line with industry best practice.

2.0 SCOPE

This instruction covers the minimum requirements that shall be followed for the testing and inspection of all distribution earthing systems in Endeavour Energy's distribution network. Endeavour Energy's distribution network comprises all assets with standard voltage ratings of 230/400V, 11kV, 22kV and 12.7kV SWER systems.

3.0 REFERENCES

- Company Policy 9.8.3 - Network Operations
- Company Policy 9.9.1 - Network Asset Maintenance
- Company Policy (Governance) 2.0.3 – Compliance
- Company Electrical Safety Rules
- EDI 001 – Earthing risk assessment
- EDI 100 – Distribution earthing design, construction and test
- SDI 528 – Substation signs and equipment labels
- SMI 101 – Minimum requirements for maintenance of distribution equipment
- Regional Workplace Instruction WRG 0619 – Methods Used to Record Test Results
- IEEE 81: 2012 - Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Grounding System
- Endeavour Energy zone substation bonding configuration list (Standards website)
- Electricity Supply Act 1995

4.0 DEFINITIONS AND ABBREVIATIONS

Accredited Service Provider (ASP)	Accredited Service Provider, or "ASP, means a person who has been accredited through a ministerially-recognised accreditation scheme to undertake contestable work.
ART	The attached rod technique (ART) is also known as the 4-pole measurement with a clamp test that can be used to measure earth resistances on live earthing systems that remain connected to alternate current paths such as common earthed systems or HV earths with cable screens or HVABC catenary connected.
CIT	Current injection tests consist of injecting a current between the earthing system under test and a remote earth and measuring the potential rise caused by this current at various locations as well as measuring the step and touch voltages at various locations.
Clearing time (primary)	The time taken for the upstream protective devices and circuit breaker(s) / fuses to isolate the source of fault current.
Clearing time (backup)	The longest time taken for the upstream protective devices and circuit breaker(s) / fuses to isolate the source of fault current assuming any one item of the protection system fails to operate.

	Protection system includes the relay, CT’s, VT’s, D.C. supplies, communications systems and CB’s.
Common or Combined Earthing	A common or combined earthing system is one in which the HV distribution and low voltage electrical equipment is earthed to a common terminal bar. This is achieved by connecting the MEN system to the HV and LV earth at the distribution substation or other distribution asset.
Conductive poles	A pole made of material that is conductive material, typically concrete or steel on Endeavour Energy's network.
Distribution network	Collection of assets (distribution lines, cables, substations and associated equipment) whose purpose is to distribute power from zone substations to distribution substations, which feed the low voltage network
Earth electrode	Uninsulated conductor installed vertically in electric contact with the Earth (through dirt of intermediate material) intended for the conduction and dissipation of current.
Earth fault (EF)	Includes a single phase to ground fault and two-phase to ground fault – a fault caused by a conductor or conductors being connected to earth or by the insulation resistance to earth becoming less than a specified value.
Earth grid	Interconnected uninsulated conductors installed in contact with the earth (or intermediate material) intended for the conduction and dissipation of current and or for the provision of a uniform voltage reference. A part of the earthing system.
Earthing conductor	Conductor intended to provide a conductive path for the flow of earth fault current for the control of voltage rise and reliable operation of protection devices.
Earthing System	Arrangement of earth conductors, typically including an earth grid, earth electrodes and additional earth conductors such as overhead earth wires, cable sheaths, earth continuity conductors (ECC’s) and parallel earthing conductors (PEC’s)
Ellipse	Endeavour Energy asset management database
EPR	Earth Potential Rise - the rise in potential of the ground around an electrical installation due to fault current flow into the ground in the event of a single phase to ground fault at the electrical installation.
Equipotential bond	A bonding conductor applied to maintain continuity of conductive structures and conductors with the main earth grid or structure in order to prevent voltage differences The equipotential bonding conductor may not be designed to carry fault current.
GIS	Geographical Information System
HV	High voltage - a voltage exceeding or equal to 1000V AC (refers to 11kV, 12.7kV and 22kV in this instruction).
LV	Low voltage - a voltage exceeding 50V AC but less than 1000V AC.
MEN	Multiple Earthed Neutral. A system of earthing in which the parts of an electrical installation required to be earthed in accordance with

	AS/NZS 3000 are connected together to form an equipotential bonded network. This network is connected to both the neutral conductor of the supply system and the general mass of earth.
Network	The Endeavour Energy electrical network of poles, wires, substations and other assets by which electrical power is transmitted/distributed to its customers.
Remote earth (reference earth)	Part of the earth considered as conductive, the electric potential of which is conventionally taken as zero, being outside the zone of influence of the relevant earthing arrangement.
Risk	The change of something happening that will have an impact on objectives. Potential for realisation of unwanted, adverse consequences to human life, health, property or the environment. Note: A risk is often specified in terms of the expected value of the conditional probability of the event occurring times the consequence of the event given that it has occurred.
SEF	Sensitive earth fault protection – A type of feeder protection designed to detect small earth fault currents due to high impedance fault paths. This form of protection may take up to 10 seconds.
Separate earthing	A system where the HV and LV earths are electrically separate
Soil resistivity	Specific resistivity of a material which is used to define the resistance of a material to current flow. It is defined as the electric field strength (Vm^{-1}) divided by the current density (Am^{-2}) which represent the value to 1 amp flowing into one metre cube of material yielding units of ohm meter (Ωm).
Special location	The ‘special’ location category implies an area within close proximity to or within a premise where there is a high likelihood that shoes will not be worn and/or the risks associated with the earthing system has the potential to be exposed to a number of people simultaneously through contact with affected metalwork. This includes (but is not limited to) schools, pre-schools, day care centres, aquatic centres, recreational swimming areas and beaches.
Step voltage (loaded)	Voltage between two points on the earth’s surface that are 1m distant from each other while a person is making contact with these points.
Step voltage (prospective)	The voltage between two points on the earth’s surface spaced that are 1 metre distant from each other, which is considered to be the stride length of a person. (Often referred to as "Prospective Step Voltage")
Substation	Part of a power system, concentrated in one place, including mainly the terminations of transmission and/or distribution lines, switchgear and housing which may also include transformers. The reference to ‘major substation’ in this document refers to all zone substations, transmission substations and switching substations with transmission voltages.

SWER	Single Wire Earth Return - a single phase electrical system where the return path for the load current is through the ground.
SWMS	Safe work method statement
Touch voltage (loaded)	Voltage between conductive parts and/or nearby soil at the feet when touched simultaneously influenced by the impedance of the person in electric contact with these conductive paths.
Touch voltage (prospective)	Voltage between simultaneously accessible conductive parts and/or nearby soil at the feet when those conductive parts are not being touched. The term touch voltage refers to prospective touch voltages unless otherwise stated

5.0 ACTIONS

5.1 General requirements

The design, selection and installation of the earthing systems for distribution systems shall confirm that the minimum performance and functional requirements below are met. The performance requirements for distribution earthing systems include:

a) Designed functioning of electrical protective devices by establishing an adequate earth impedance path is available for lightning, switching surges, fault and power frequency current whilst minimising mechanical damage and maintaining redundancy
b) Managing the risks associated with step, touch and transfer voltages in accordance with this instruction, applicable regulations, standards and guidelines
c) Avoidance of inadvertent interference, theft and chemical deterioration

All earth system testing shall be carried out in accordance with Company Electrical Safety Rules and relevant Safe Work Method Statements. These documents cover safe approach distances and techniques required to safely perform the test.

5.2 Routine maintenance tests

The routine maintenance intervals for all distribution equipment are set out in SMI101. Where either routine earth grid inspections or resistance tests are due, the following requirements shall apply.

5.2.1 Routine earthing system inspection

All accessible earth terminations shall be inspected to identify loose or corroded components. The following key items shall be assessed.

Table 5-1: Earthing system inspection requirements

Item	Applicable asset	Criteria
Lugged terminations	All	- Bolt is tight - Conductor is tightly crimped within the lug and not corroded - Lug face is flat to surface (no washer or nut between face and equipment or earth bar)
Earthing configuration		- Confirm the earthing configuration (common or separate) recorded in Ellipse (or construction drawing if available) matches the earthing configuration of the asset by a continuity test.
Warning Labels		- Each earth cable is labelled and marked according to drawing 348245.
Earth down leads	Pole mounted assets	- Down lead is unbroken and not corroded - Earth batten is intact and no physical damage observed

Item	Applicable asset	Criteria
Surge Arresters		- No physical damage observed on the surge arresters
Cable screen terminations	First UGOH from a ZS	- Cable screen termination is bonded to the UGOH earth - Bond between the UGOH earth and LV neutral match the requirements of the design
	First padmount substation or switching station from a ZS	- Cable screen terminations of ZS feeder cable match the requirements of the design (Cable screens must be bonded to earth at both ends if CMEN connected site)
	All subsequent padmounts directly connected to CMEN connected ZS via cable	- Cable screen terminations are bonded to the padmount earth bar at both ends

5.2.2 *Routine earthing system test*

During routine earth grid maintenance tests, the inspection requirements in section 5.2.1 shall be carried out prior to any test. All measured earth resistance test values shall be recorded in Endeavour Energy's asset database (Ellipse).

All earthing conductors shall be tested to confirm no HV exists prior to earthing system test. The earthing conductors shall then be tested to confirm no current and a voltage of less than 30V exists on the earthing conductors. If the conductor is energised then appropriate isolation and access authority shall be obtained.

The type of earth resistance test required will vary depending on the type of distribution asset and the earthing configuration. See Table 5-2 for the required test methodology for each situation.

Table 5-2 - Earth resistance test method required (see Appendix 1-3 for test methodology)

Asset	Configuration	Earth	Live Test	Alternate Live Test	Outage Test	Ellipse field to be recorded
Padmount and Poletop substations (including indoor)	Common	Common	Clamp on test[1]	ART	FOP[3]	Common Earth Resistance Value (Ω)
	Separate	HV	Clamp on test[2] **or** FOP[3]	ART	FOP[3]	HV Earth Resistance Value (Ω)
	Separate	LV	Clamp on test[1]	ART	FOP[3]	LV Earth Resistance Value (Ω)
Switching Stations	Common/ Separate	HV/ Common	Clamp on test[2]	ART	FOP[3]	Common Earth Resistance Value (Ω)
SWER substation/	N/A	HV	FOP[3]	ART	FOP[3]	HV Earth Resistance

[1] The clamp on test shall only be used if the number of MEN connected customers is greater than 30 and if the asset is a padmount the commissioning year of the substation is post- 2012. Padmount substations constructed prior to 2012 are not designed for clamp on testing and will not yield a valid reading.

[2] A temporary bridge shall be connected between the HV and LV earthing systems and that the number of MEN connected customers shall be greater than 30

[3] Earth grid shall be isolated and that no other HV earthing systems are connected such as HVABC or cable screens

Asset	Configuration	Earth	Live Test	Alternate Live Test	Outage Test	Ellipse field to be recorded
isolating TX						Value (Ω)
	N/A	LV	FOP[3]	ART		LV Earth Resistance Value (Ω)
UGOH, LBS, Auto-recloser	Common	N/A	Clamp on test[1]	ART	FOP[3]	HV Earth Resistance Value (Ω)
	Separate	N/A	Clamp on test[2] **or** FOP[3]	ART	FOP[3]	HV Earth Resistance Value (Ω)
HVABC	N/A	N/A	Clamp on test[1]	ART	FOP[3]	HV Earth Resistance Value (Ω)

Refer to Appendix 1-3 for various procedures on carrying out earthing resistance tests. In cases where access to the earths is prohibited due to switchgear, the test shall be performed with a scheduled outage for access to the earths.

Where a common earthed padmount substation may have multiple earth conductors (usually three) connected to the LV earth bar without any labelling or traceability, the common earth conductor can be identified by using the clamp on method on each conductor to identify which one has a different resistance to the other two conductors which is usually the two bonds from the HV side.

If the asset has a separate earthing arrangement the clamp on test shall only be conducted after checking that no hazardous standing voltage exists between the HV and LV earth bars and a temporary bridge connection installed between the HV and LV earth bars. This test assumes that the impedance of the MEN is small compared to that of the local electrodes.

5.2.3 Interpretation of test results

The continuity test for a common earthed asset shall yield a value of less than one (1) ohm between the LV neutral and the HV earth conductor/bar. If the continuity test yields a value greater than one (1) ohm, then the connection between the LV neutral and HV earth conductor/bar can be restored immediately if the asset is isolated and de-energised. For live assets, the asset shall be listed as a defect, recorded with a maintenance work order and prioritised in accordance with the details of SMI124 – Maintenance data entry and defect prioritisation.

If the live clamp on test does not yield any reasonable result, an outage shall be organised to perform a fall of potential test for more accurate resistivity readings.

The resistance test results shall be verified to be within 80% and 120% of the designed earth resistance. If the designed earth resistance is not available then the maximum limit on resistance shall be 100Ω. If the test result does not meet this criteria, it must be listed as a defect, recorded with a maintenance work order and prioritised as follows in accordance with the details of SMI124 – Maintenance data entry and defect prioritisation:

- HV earth resistance greater than 100Ω
    - In a frequented location: Defect Category 2
    - In a non-frequented location: Defect Category 3

- LV earth resistance (separately earthed asset) greater than 100Ω: Perform fault loop impedance test on the closest MEN connected customer.
    - If test fails, list asset as Defect Category 1
    - If test passes, list asset as Defect Category 3
- Earth resistance above 120% of the designed earth resistance: Defect Category 3

Following the identification of a non-compliant design and the registration of the defect in Ellipse the results shall be reported to the design office. Regional Services (design office) shall then assess the site for safety compliance against EDI100 requirements with the tested earth resistance. If the site complies no further action is required and the defect can be closed, otherwise the existing earth grid shall be replaced with a designed compliant grid.

5.3 Commissioning inspection and tests

All distribution assets shall be inspected and tested prior to commissioning. The inspection requirements in section 5.2.1 and the test requirements in section 5.2.2 shall be carried out as a minimum. All commissioning test results shall be recorded in Ellipse as measured earth resistances.

For accuracy, the FOP or ART test method shall be used prior to commissioning. The clamp on method shall be then conducted once the earthing system is in its final 'in-service' configuration. Comparing subsequent clamp-on test results with the 'as commissioned' clamp on test results should indicate if the resistance of the local earthing has changed significantly. The results of this test shall be recorded into Ellipse.

The earth resistance test results prior to commissioning shall meet the requirements of the design. Where the requirements of the design are not met, the designer shall be consulted.

5.4 Tests for design

Various test results may be required to supplement the design process of a distribution asset. These tests will typically be either an earth resistance test or a current injection test. Where the requirements of the design are not clearly stated on the drawing, the designer shall be consulted and resistance values recorded on associated drawings. The specific requirements of these tests will depend on the requirements of the designer.

5.5 Current Injection Test (CIT)

For designs that are unable to achieve compliance through calculations and modelling, a current injection test may be required to identify actual prospective touch, step and transfer voltages in an event of an earth fault. Where a CIT is required, the following requirements shall apply.

5.5.1 Scope of test

The following tests shall be conducted where current injection testing is required on a distribution earthing system (refer to Annexure 4 for full methodology):

- Earth potential rise (EPR) test
- Prospective step, touch and hand to hand voltages measured at locations expected to be the worst case
- Transferred voltages on surrounding metallic infrastructure (fences, pipelines etc.)
- Identify return current paths and splits

5.5.2 Before commencing test

Where possible, the following design information and measurements shall be obtained before the site inspection:

- Soil resistivity measurements
- As installed distribution substation bonding arrangement
- The location of all services in the vicinity of the site through the DBYD[4] service
- Possible routes for EPR run

If telecommunications assets are identified to be in the vicinity of the asset at test, telecommunications power coordination officers shall be informed of the test date to identify during the test any potential touch voltages existing on their assets.

5.5.2.1 Soil electrical resistivity

Soil resistivity test shall be carried out prior to undertaking the current injection test to allow the determination of the applicable voltage criteria and expected performance of the earthing system (Refer to Annexure 5: Soil Resistivity test methodology for more information on testing requirements).

5.5.2.2 Distribution Substation bonding arrangement

The bonding arrangement of the substation can be obtained from Ellipse and confirmed via inspection or through a continuity test prior to carrying out the CIT test.

5.5.2.3 Dial before you dig

The location of all services[4] in the vicinity of the site, including LV street supplies, Telstra, communications, water, sewer, gas and other pipelines is recommended to be obtained and kept on site during the test. If any form of digging is deeper than 300mm below ground, DBYD is required under the Energy Supply Act.

5.5.2.4 Establish the routes

Where feasible, the route of the earth potential rise (EPR) runs shall be at right angles to the direction of the injection current to reduce the effects of induction in the test leads. EPR lead runs shall be performed in at least two (2) directions if practical, identifying and managing any traffic or pedestrian management issues or hazards. Additionally, locations close to MEN, rails and metallic pipelines shall be avoided where possible due to interference. These route plans shall be established prior to undertaking the test.

5.5.2.5 Protection information and allowable voltage criteria

Protection information including fault levels and clearing times for the site under test shall be requested prior to undertaking the test. The limits for step and touch potentials and transfer potential hazards shall be calculated in accordance to EDI001 – Earthing Design Risk Assessment prior to the test and be based upon primary protection fault clearing times.

5.5.3 Measurements

After the current injection circuit has been setup, the following measurements shall be taken and recorded as part of the assessment.

5.5.3.1 Prospective and loaded touch and step voltages

Prospective step and touch voltages shall be measured around the asset under test and where transferred voltage hazards are expected to occur and where personnel are likely to be exposed to the voltages in the event of an earth fault.

Prospective touch voltages shall be measured at the following potential hazardous locations:

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[4] Maps are available from Dial Before You Dig the service <http://www.1100.com.au/>

- Adjacent metallic fences/gates
- Private swimming pools (within a 30m radius)
- Conductive poles near bus stops or highly frequented pedestrian walkways
- At bus stops or locations that are frequented by persons
- Exposed metallic pipelines

Prospective step voltages shall be measured at the following locations:

- Area surrounding the asset
- Private swimming pools (within a 30m radius)

Loaded touch and step voltages shall only be measured and recorded if prospective touch and step voltage measurements do not meet allowable voltage criteria in accordance to EDI001 – Earthing Design Risk Assessment. Particular attention shall be paid to test measurements at special locations as defined in EDI001 Earthing Design Risk Assessment.

Prospective and loaded touch and step test measurements are to be made using driven rods and a voltmeter suitable for the test frequency.

5.5.3.2 Earth potential rise (EPR) test

Using the fall of potential method, the voltage difference shall be measured between the local earth grid and various points on the surface of the soil from 1 metre up to the point where the potential electrode leaves the earth grid's area of influence (remote earth). This can be identified when the EPR measured reaches a plateau for a minimum of three (3) measurements, or until it becomes impractical to continue.

The EPR shall be measured in a direction that is perpendicular to the current injection circuit. All measurements shall be recorded and scaled to the actual fault current and frequency.

5.5.3.3 Identify return current paths and splits

An ammeter tuned to test frequencies shall be used to measure the current in all possible current paths returning to the substation under test. A reference voltage signal or GPS time signal shall be used to determine the phase angle of all current measurements referenced to the injection current. Using the phase angles and current magnitudes measured, the current splits measured shall be summed to determine the remaining fault current flowing into the earth grid.

5.5.4 Calculation of Earthing System Impedance

The grid impedance can be calculated by using the equation below:

$$Z_{Grid} = V_{EPR}/I_{Grid}$$

Where; $I_{Grid} = (I_{test}) - (I_{Cable\ Sheath}\angle\varphi) - (I_{neutral}\angle\varphi)$

V_{EPR} = the voltage measured to remote earth during the EPR run

5.5.5 Reporting of test results

All inspection and test results shall be recorded into an appropriate report and the following minimum information presented in the report:

- Summary of test results highlighting any non-compliances;
- Prospective step and touch voltage allowable limits;
- Step, touch and grid prospective voltages measured and scaled to true fault levels;
- Loaded touch voltage allowable limits;

- Loaded touch voltages measured and scaled to true fault levels;
- Indicate if the step, touch and grid voltages are a pass or fail;
- A description of the test arrangement and any important considerations taken into account;
- Earth test current split measurements and vector summation;
- Measured/calculated earth grid impedance;
- EPR measurements table and graph (voltage vs distance from earth grid);
- Earth resistivity table graph (ohmmeters vs depth in meters);
- Map of location and route of feeder used for the injection current;
- Map showing the asset boundary, the 430V contour lines and the location of any Telstra assets, water services, pipelines or earthed structures or assets in the immediate area;
- Map showing EPR routes with respect to current injection path;
- Photographs of the site and any problems or defects identified; and
- Conclusion and recommendations by the testing officer.

5.6 Soil Resistivity Test

The purpose of measuring soil resistivity (ρ) is to determine the electrical characteristics of the soil in which the earthing system will be installed. Generally, a two layered electrical soil model is sufficient to determine how current will behave for distribution earthing systems.

The Wenner 4-pin method shall be used to determine the soil electrical resistivity, unless it is deemed impractical, and the designer has a solid knowledge of an alternate method.

5.6.1 Test requirements

The following are the soil resistivity test requirements:

- It is recommended that the Dial Before You Dig (DBYD) service is performed 48 hours prior to the test to allow identification of buried services that may cause contribute to false readings. All underground services shall be avoided while performing the test.
- The test shall be performed in a straight line and spacing of equal interval between electrodes from 1m up to at least 20m is required, generally doubling the separation after each reading. If proposed earthing design is greater than 10m deep, the test spacing must be at least twice the depth of the proposed earthing.
- As measuring results are often distorted and corrupted by underground metallic infrastructure, a second test run, performed perpendicular to the first run, is required. If this is not practicable due to space restrictions, the second run shall be performed in different location but close enough to get a useful indication of the soil model at the location of the asset.
- As the resistivity of the top soil changes quite rapidly with moisture content, the ground measured shall be dry during testing, and shall not have had any rainfall in the last 48 hours.
- For common earthed designs the test must be performed in wide open areas near the wider MEN the asset is connected to, such as parks and ovals where practical. For separately earthed designs, the test must be performed as close as possible to the existing/proposed location of the asset. The location of the test probes shall be as far as possible from any buried structures. Where the presence of buried metallic structures is suspected in the area where the soil resistivity measurements are to be taken and the location of these structures is known, the test probes shall be aligned in a direction

perpendicular to the routing of these structures. The second test shall then be performed in a separate location.

- The soil resistivity results must be calculated, recorded and plotted on a graph so that any deviations in the data can be identified as they occur and further investigated if necessary. These can be done using Endeavour Energy's EDI100 3E Tool.

5.6.2 Interpretation of results

The Wenner 4-pin method shall provide the same results when the current and voltage electrodes are reversed. This reading shall also be taken for each spacing, as where there is a significant difference between forward and reverse configuration readings it indicates that either something is wrong with the test configuration, or there is external interference such as a buried conductive structure (see Annexure 5 for full methodology).

The results from the two (2) test runs shall show consistency to minimise the effect of metallic infrastructure on the test results. If no clear soil pattern can be seen or the results vary unaccountably from typical values for the type of soil being measured, the measurements should be re-checked or introduce intermediate probe spacing, or the anomalies should be accounted for and reported.

6.0 AUTHORITIES AND RESPONSIBILITIES

General Manager Asset Management has the final authority and responsibility for:

- Approving this standard and the earth testing methodology to be applied to distribution assets associated with Endeavour Energy's network

Manager Asset Standards and Design has the authority and responsibility for:

- Determining whether this standard meets company policy, regulatory and the health and safety obligations of Endeavour Energy

Earthing and Power Quality Manager has the authority and responsibility for:

- Confirming that the content of this instruction is kept up to date based on industry best practice and current research and literature regarding distribution earthing testing procedures

Manager Network Connections has the authority and responsibility for establishing that:

- Contract inspectors test the earth systems in accordance with the design and this standard;
- Data is uploaded into the Ellipse and GIS databases where such data is forwarded by the ASP

Distribution Managers are responsible for establishing that:

- Earthing tests are carried out in accordance to this standard;
- Earthing related data is uploaded into the Ellipse and GIS databases

Regional Service Managers are responsible for establishing:

- Earthing related data is uploaded into the Ellipse and GIS databases;
- Test results comply with the design and this standard;
- The work performed is carried out in accordance with local and statutory requirements

7.0 DOCUMENT CONTROL

Documentation content coordinator: Earthing and Power Quality Manager

Documentation process coordinator: Branch Process Coordinator

Annexure 1: Fall of Potential (FOP) Test

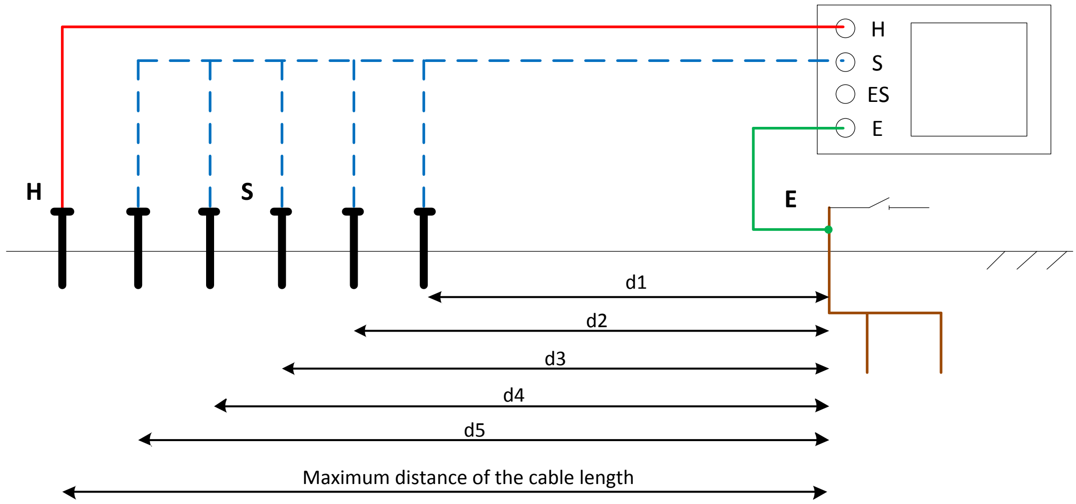


Figure 1-1: Fall of potential test arrangement

Scope of Test

The 3 point fall of potential (FOP) test is used to measure the earth resistance of an isolated earth system with two (2) auxiliary electrodes. It is not suitable to determine the local earth resistance of LV or common earthing systems, or HV earthing systems where alternate fault current paths such as cable screens or HVABC catenary connected to the earth system under test, unless an outage is scheduled and isolation of the local earth carried out safely.

For new installations, earth grids shall be tested before connection to any other earths, such as LV neutrals and HV cable sheaths. If there is uncertainty as to whether alternate current paths exist, the attached rod technique (ART) shall be used (see Annexure 2).

Test Method

1. Place auxiliary electrodes in a straight line from the earth electrode under test. The line of test shall not run in parallel or close to any known underground metallic infrastructure or fences as far as reasonably practical.
2. The distance between the current electrode H and the earth electrode E should be 8 to 10 times the depth of the earth electrode tested. In most cases the depth of the earth electrode is unknown, thus the entire cable length shall be unravelled and current electrode H inserted into the ground as far away as possible to prevent:
    a. overlapping of the effective resistance areas of the earth electrode E and the current electrode H
    b. Induction effects in wound cable
3. Connect the cables to the terminals of the test unit for the auxiliary electrodes and the earth electrode under test.
4. Perform measurements at a minimum of 5 locations where the distance between the potential electrode S and the earth electrode E is in the range of 50% - 90% of the distance between the current electrode H and the earth electrode E (for example, 50%, 60%, 70%, 80% and 90% of the total distance).
5. Plot these 5 measurements to identify the plateau for the actual resistance of the earth electrode (refer Annexure 7).
6. If the plateau cannot be clearly identified, perform further measurements or extend the cable length such that the current electrode H is placed further away from the earth electrode E and test repeated.

If the test equipment yields an invalid reading, the following amendments to the setup may be performed:

- Drive additional rods and interconnect them in parallel to reduce the impedance of the auxiliary electrode
- Increase the depth of the auxiliary electrode
- Check connections
- Stamp down the soil directly around the auxiliary electrode to remove air gaps formed when inserting the rod.
- Pour water around the auxiliary electrodes. This reduces the auxiliary electrode's contact resistance without affecting the measurement.

Staff shall be trained in the use of the test instrument and maintain proper clearances when performing the test. The manufacturer's instructions shall be followed to confirm the correct connections are made. The line of test shall avoid any known underground metallic infrastructure as far as reasonably practical.

Annexure 2: Attached Rod Technique (ART) Test

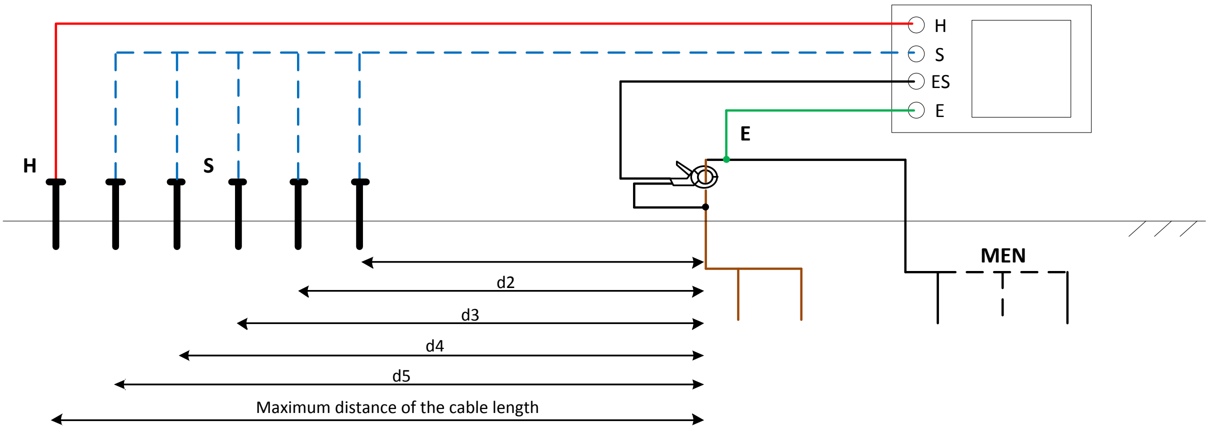


Figure 2-1: Attached Rod Technique test arrangement

Scope of Test
The attached rod technique is also known as the 4-pole measurement with a clamp test that can be used to measure earth resistances on live earthing systems that remain connected to alternate current paths such as common earthed systems or HV earths with cable screens or HVABC catenary connected. The ART utilises either a flexible Rogowski coil or a clamp on current transformer (CT) to measure the current injected into the earthing system.

Where feasible, the ART is preferred over the clamp on test due to its high accuracy and independence of a dense MEN network.

Test Method
1. Place auxiliary electrodes in a straight line from the earth electrode under test. The line of test shall not run in parallel or close to any known underground metallic infrastructure or fences as far as reasonably practical.
2. The distance between the current electrode H and the earth electrode E should be 8 to 10 times the depth of the earth electrode tested. In most cases the depth of the earth electrode is unknown, thus the entire cable length shall be unravelled and current electrode H inserted into the ground as far away as possible to prevent:
    a. overlapping of the effective resistance areas of the earth electrode E and the current electrode H
    b. Induction effects in wound cable
3. Connect the cables to the terminals of the test unit for the auxiliary electrodes and the earth electrode under test. Connect the clamp to the path of the earth electrode E and the other reference lead to the same point.
4. Perform measurements at a minimum of 5 locations where the distance between the potential electrode S and the earth electrode E is in the range of 50% - 90% of the distance between the current electrode H and the earth electrode E (for example, 50%, 60%, 70%, 80% and 90% of the total distance).
5. Plot these 5 measurements to identify the plateau for the actual resistance of the earth electrode (refer Annexure 7).
6. If the plateau cannot be clearly identified, perform further measurements or extend the cable length such that the current electrode H is placed further away from the earth electrode E and test repeated.

If the test equipment yields an invalid reading, the following amendments to the setup may be performed:
- Use multiple rods to reduce the impedance of the auxiliary electrode

- Check connections
- Stamp down the soil directly around the auxiliary electrode to remove air gaps formed when inserting the rod.
- Pour water around the auxiliary electrodes. This reduces the auxiliary electrode's contact resistance without affecting the measurement.

Staff shall be trained in the use of the test instrument and maintain proper clearances when performing the test. The manufacturer's instructions shall be followed to confirm the correct connections are made.

Annexure 3: Clamp On Test

Scope of Test

The Clamp on Test uses two clamps to measure the earth resistance of earthing systems with parallel earth connections and can be performed while the supply is still energised. The first clamp H applies a voltage to the circuit while the clamp ES measures the current flowing into the earth electrode.

For padmounts, the clamp on test shall only be performed on those built post-2012 due to interference from adjacent bare earth conductors that cause leakage currents to flow back via these conductors and not the local earth, resulting in a much lower than actual earthing loop impedance. For pre-2012 built padmounts, the ART or FOP test shall be used.

The clamp on test can be performed easily with common earthed assets, however separately earthed assets require a bridging conductor to complete the loop circuit via the MEN. The minimum required number of MEN connected customers is 30. If the number of MEN connected customers is less than 30, either the FOP or ART test shall be performed.

When performing a clamp on test on a pole substation, if the clamps cannot be fitted around the earth due to physical constraints, the following options shall be considered:

- the clamps shall be placed at a location where the earth diverts off the pole to connect to the substation
- the use of a wraparound current sensor cable (Rogowski coil)

The following instructions demonstrate the clamp on test method for separately earthed assets. For an alternative test method see Annexure 2: Attached Rod Technique (ART) Test.

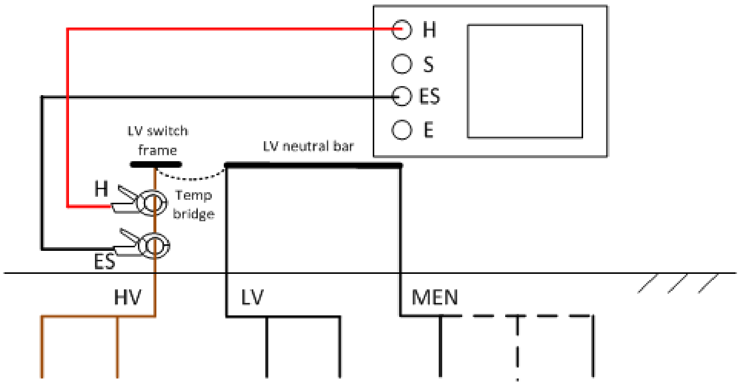


Figure 3-1: HV earth test - separate earth padmount/switching substation

Testing HV earth system of separately earthed padmount/switching substation

1. Install temporary bridge between the LV neutral bar and LV switch frame.
2. Connect both clamps onto the HV earthing system. The clamps shall be placed as far apart as reasonably practical to avoid direct electromagnetic influences between the transmitting clamp and the receiving clamp.
3. Connect the cables of the clamps to the terminals of the test unit.
4. Perform the test

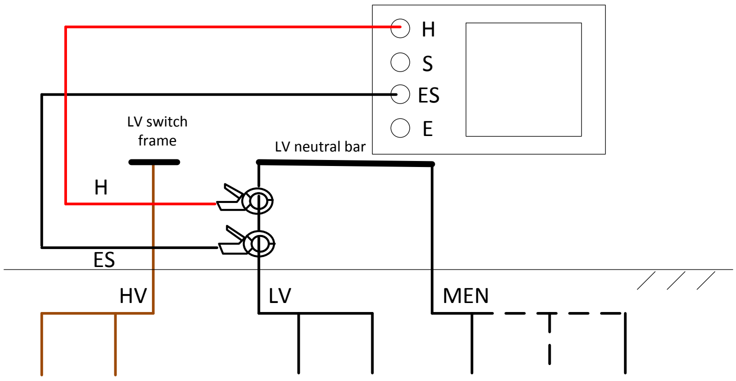


Figure 3-2: LV earth test - separate earth padmount/switching substation

Testing LV earth system of separately earthed padmount/switching substation

1. Remove any temporary bridge between the LV neutral bar and LV switch frame.
2. Connect both clamps onto the LV earthing system. The clamps shall be placed as far apart as reasonably practical to avoid direct electromagnetic influences between the transmitting clamp and the receiving clamp.
3. Connect the cables of the clamps to the terminals of the test unit.
4. Perform the test

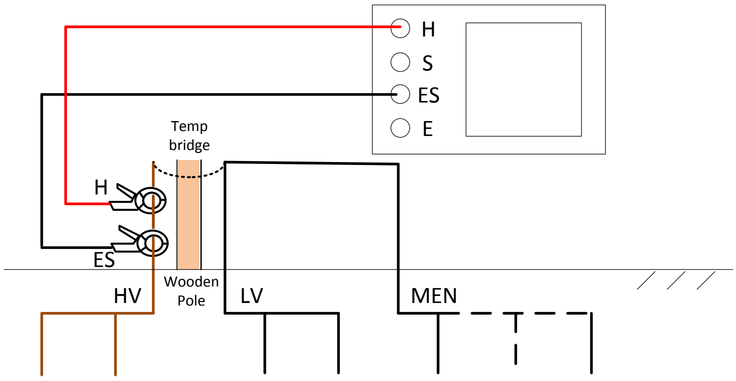


Figure 3-3: HV earth test - separate earth pole substation/UGOH/LBS wooden pole

Testing HV earth system of separately earthed pole substation/UGOH/LBS on wooden pole

1. Install temporary bridge between the HV earth cable and LV earth cable at the test point, located approximately 2.7m to 4m above ground.
2. Connect both clamps onto the HV earthing system. The clamps shall be placed as far apart as reasonably practical to avoid direct electromagnetic influences between the transmitting clamp and the receiving clamp.
3. Connect the cables of the clamps to the terminals of the test unit.
4. Perform the test

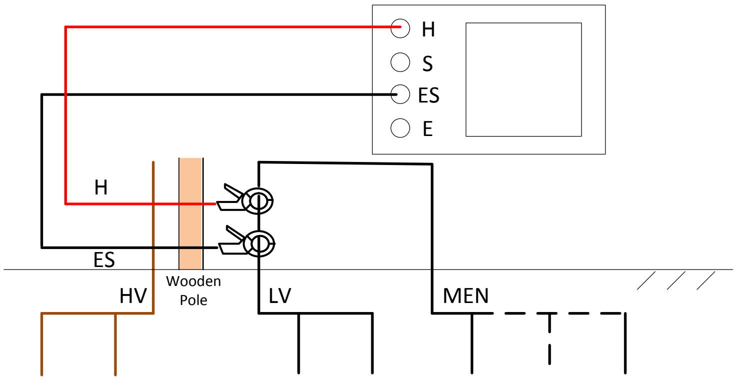


Figure 3-4: LV earth test - separate earth pole substation/UGOH/LBS wooden pole

Testing LV earth system of separately earthed pole substation/UGOH/LBS on wooden pole

1. Remove any temporary bridge between the HV earth cable and LV earth cable.
2. Connect both clamps onto the LV earthing system. The clamps shall be placed as far apart as reasonably practical to avoid direct electromagnetic influences between the transmitting clamp and the receiving clamp.
3. Connect the cables of the clamps to the terminals of the test unit.
4. Perform the test

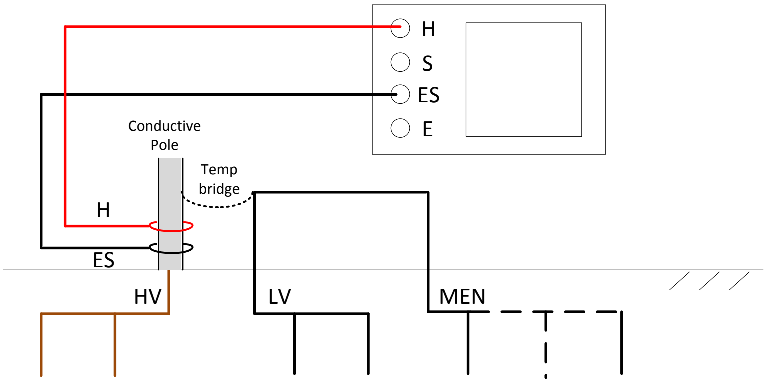


Figure 3-5: HV earth test - separate earth pole substation/UGOH/LBS concrete pole

Testing HV earth system of separately earthed pole substation/UGOH/LBS on conductive pole

1. Install temporary bridge between the HV earth ferrule of the conductive pole and the LV earth cable at the test point located approximately 2.7m to 4m above ground.
2. Connect wraparound current sensor cables around the conductive pole. If an LV earth is attached to the pole, the sensor cables shall avoid wrapping around the LV earth. The sensor cables shall be placed as far apart as reasonably practical to avoid direct electromagnetic influences between the current sensor cables.
3. Connect the current sensor cables and necessary attachments to the terminals of the test unit.
4. Perform the test

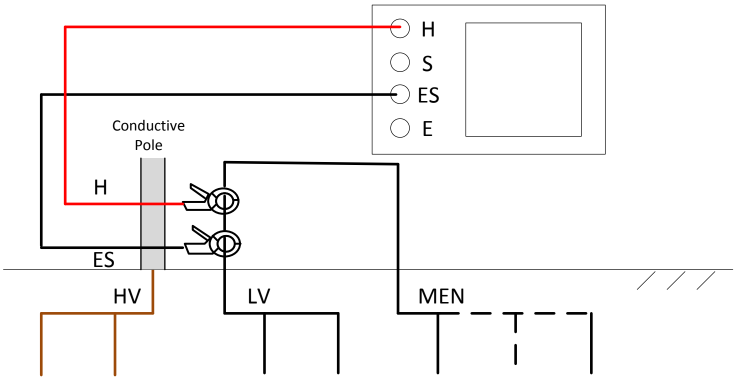


Figure 3-6: LV earth test - separate earth pole substation/UGOH/LBS concrete pole

Testing LV earth system of separately earthed pole substation/UGOH/LBS on conductive pole

1. Remove any temporary bridge between the HV earth ferrule of the conductive pole and the LV earth cable.
2. Connect both clamps onto the LV earthing system. The clamps shall be placed as far apart as reasonably practical to avoid direct electromagnetic influences between the transmitting clamp and the receiving clamp.
3. Connect the cables of the clamps to the terminals of the test unit.
4. Perform the test

Annexure 4: Current injection test (CIT) methodology

The test principle will be based on the fall-of-potential method, which consists of injecting a current between the earthing system under test and a remote earth and measuring the potential rise (see Vm in Figure 4-1 below) caused by this current at various locations as well as measuring the step and touch voltages at various locations (refer section).

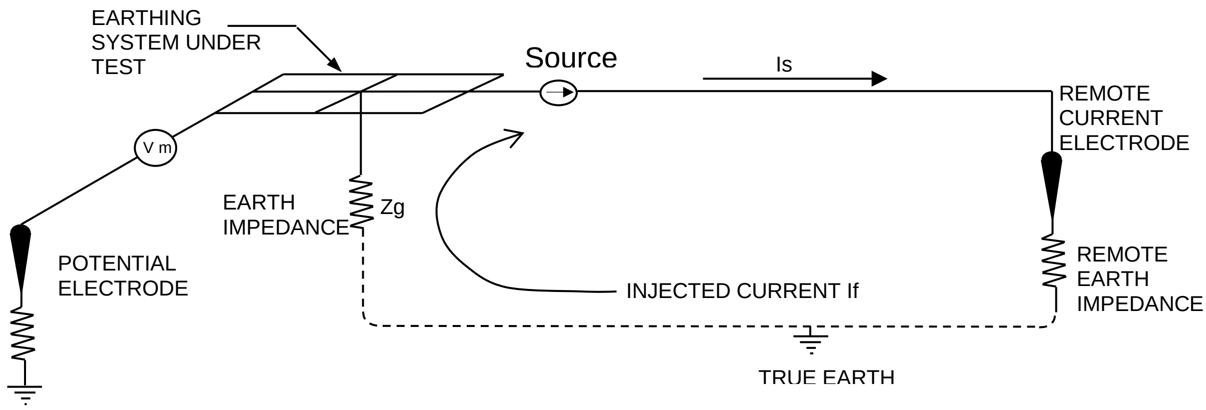


Figure 4-1: Fall-of-potential basic circuit

Is - Injection current at test frequency – usually at 53 or 56 hertz

Vm - Voltage measurements (EPR) between the earth surface layer to the earth grid at locations away from the earth grid with constant test current injected into the earthing system. This series of voltage measurements shall be used to plot voltage contours.

Fault current injection circuits

To test the integrity of the earthing system for an 11/22kV system fault at a particular asset there are two injection circuit options. Test results shall be scaled according to the ratio of the injection test circuit to the actual prospective fault current.

Method 1: Current injection test with feeder outage

The ideal injection circuit is to inject current over the actual fault circuit from the zone substation to the asset under test. This will enable the test results to closely match the actual performance of the system. As this will require a feeder outage up to the asset, it is understood that this will normally not be available, but shall be used where possible.

Once an Access Authority for Test in accordance with the Electrical Safety Rules has been issued over the feeder and asset under test, the current injection source may be installed either at the zone substation or at the asset under test. A circuit shall be established with a short circuit to earth at the opposite end to the injection unit to create a current path along one phase conductor and back through the earthing system (see Figure 4-2).

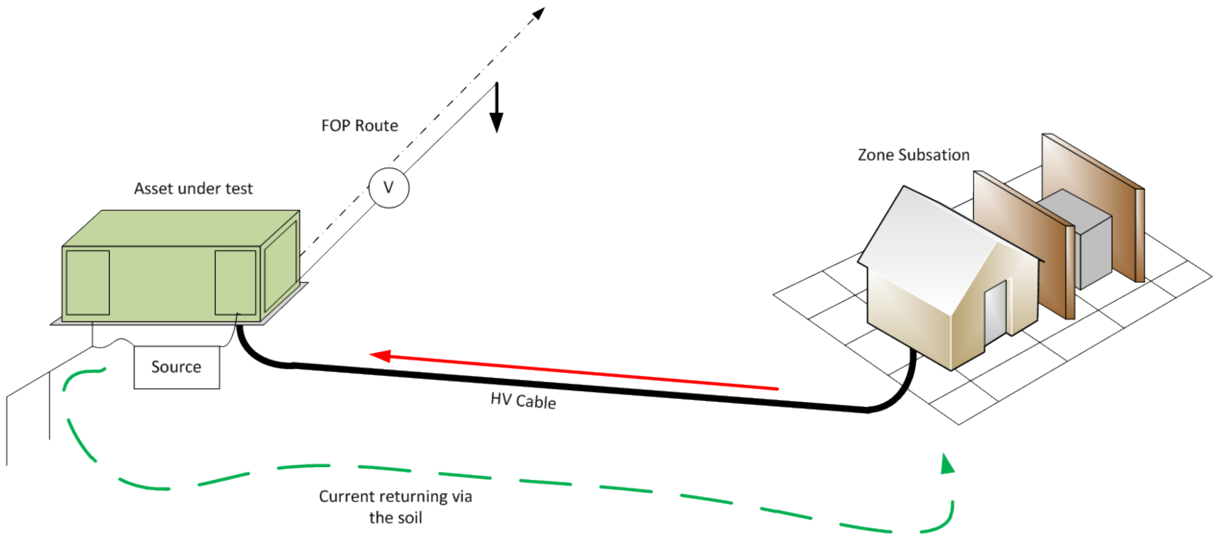


Figure 4-2: Current injection circuit with feeder outage

Method 2: Current injection test by overland lead

Where it is impractical to obtain a feeder outage between the asset under test and the source zone substation, the current injection test shall be performed by overland lead. In this situation, a test lead is run to a remote earth grid to establish the injection circuit. Care shall be taken in the selection of a remote earth grid to minimise the effects of mutual impedance and any voltage hazards.

Remote earth grids may either be:

- Separately earthed, standalone earth grids. For example: a load break switch or
- A driven stake in a location away from metallic infrastructure (for example; in a reserve)

Prior to the use of any other remote earth grid other than those stated above, the effects of mutual impedance and voltage hazards shall be assessed and approval shall be requested from the Earthing & Power Quality Manager.

In order maintain public safety, any exposed touch voltage due to the test current/voltage shall remain below 50V unless these hazards are guarded for the duration of the test.

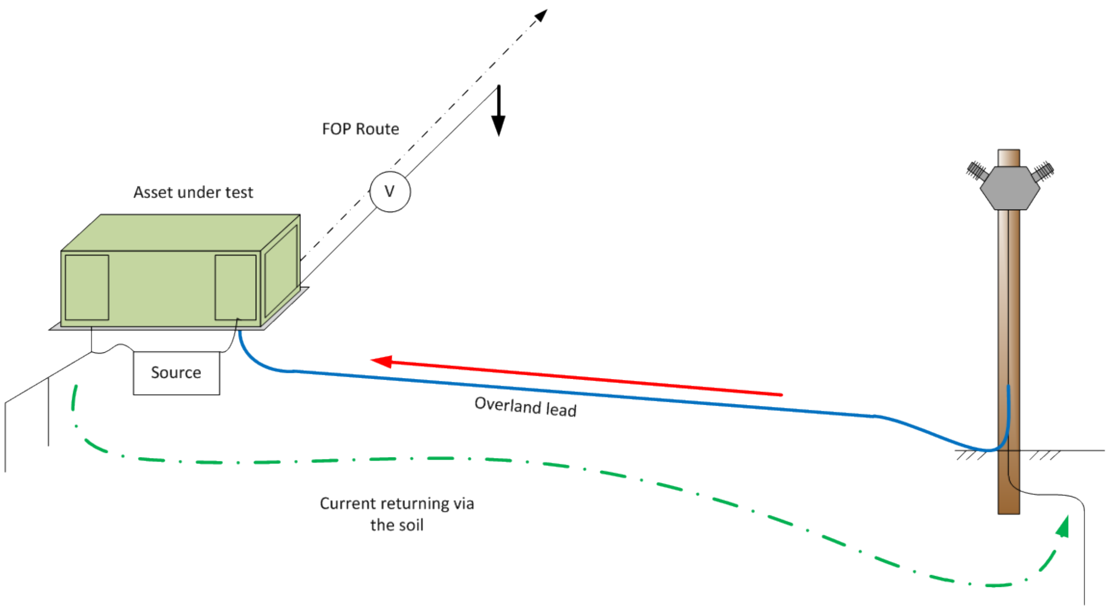


Figure 4-3: Current injection circuit using overland lead

Annexure 5: Soil Resistivity Test: Wenner 4-pin method

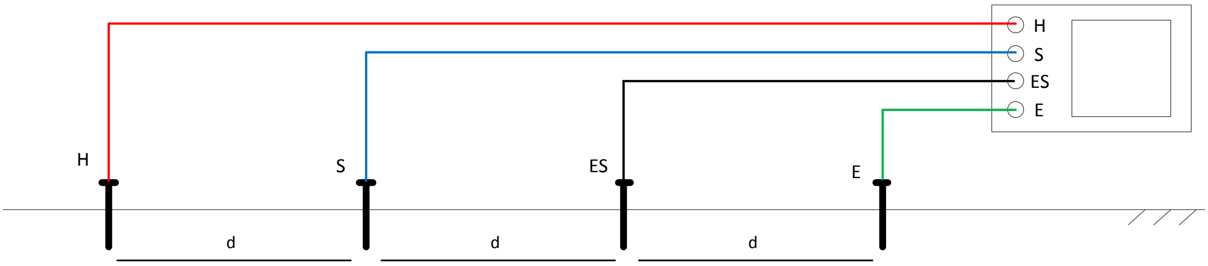


Figure 5-1: Soil Resistivity test arrangement

The following is the method to perform a soil resistivity test using the Wenner 4-pin method.

1. Set out four (4) test electrodes in a straight line and space them at equal intervals of ('a') metres, from 1 metre up to at least 20 metres (generally doubling the separation after each reading, for example, 1m, then 2m and so on).
2. Drive the electrodes into the ground to a maximum depth of 'a'/20 metres. There is no minimum depth, however, in high soil resistivity areas; a reading may not be possible at shallow depths. Recommended maximum depth is 500mm.
3. Connect the electrodes and test equipment (or earth – tester) as shown in Figure 5-1 with the electrodes configured as: Current – Potential – Potential – Current (CPPC)
4. Operate the test equipment. Reverse the electrode configuration (voltage electrodes on the outside, current electrodes on the inside - PCCP) and retest.
5. Calculate the soil resistivity from:
   $\rho_a = 2\pi a R$ where:
   ρ_a = apparent soil resistivity, in ohm metres (Ω.m)
   a = distance between electrodes, in metres (m)
   R = reading of test equipment or null meter, in ohms (Ω)
6. Record both the reading and calculation for each separation
7. Perform the second test by rearranging the test electrodes so that the second test run is perpendicular to the first test run. If this is not possible due to space requirements, perform the second test in a different location.
8. Repeat steps 4 to 6
9. Plot the calculated apparent resistivity against measurement spacing on log/log graph paper (refer Annexure 6)

Establishing a soil model

Once measurements are taken, a two layered soil model shall be established. This may be established using a computer package, or by fitting a curve to the plotted results. Endeavour Energy's EDI100 3E Tool may be used to establish a two-layer soil model from field measurements.

Typical soil resistivity values

Note: These are provided as a guide only and do not remove the need for a soil resistivity test to be carried out for each design.

Area	Soil	*Soil resistivity range (Ω-m)*	
		Lower range	Upper range
Parklea	Dry clay soil	20	100
Arndell Park, Hoxton Park, Narellan	Damp clay soil	10	20
Prospect Reservoir	Damp clay and shale	5	100
Glenmore Park	Dry clay over shale or sandstone	10	70
Parramatta	Sandy clay over sandstone	20	100
Anzac Village-Moorebank	Sandy fill	5	100
Springwood-Lower Blue Mountains	Sandy loam and sandstone	300	500
Cordeaux	Sandy loam	500	1,000
Mt Ousley	Ironstone	1,000	4,000
Mt Hay- Upper Blue Mountains	Sand-sandstone	3,000	5,000
Katoomba North-Medlow Bath	Sand-sandstone	6,000	30,000

Known areas with high soil resistivity in excess of 400 ohm-metres

Southern Region	Northern Region	Central Region
Helensburgh Darkes Forest Mangerton Kangaroo Valley Nowra Kiama Culburra Bawley Point	Kandos Mt Victoria Blue Mountains Springwood Penrith FSC Mt Wilson Bilpin Mt Tomah Kurrajong Heights Colo Lower Colo Wisemans Ferry St Albans	Oakdale South Picton Appin Campbelltown near Georges River Elderslie Chipping North Moorebank Wingecarribee Shire Moss Vale Robertson Wingello

Annexure 6: Soil Resistivity Test Sheet

Endeavour Energy

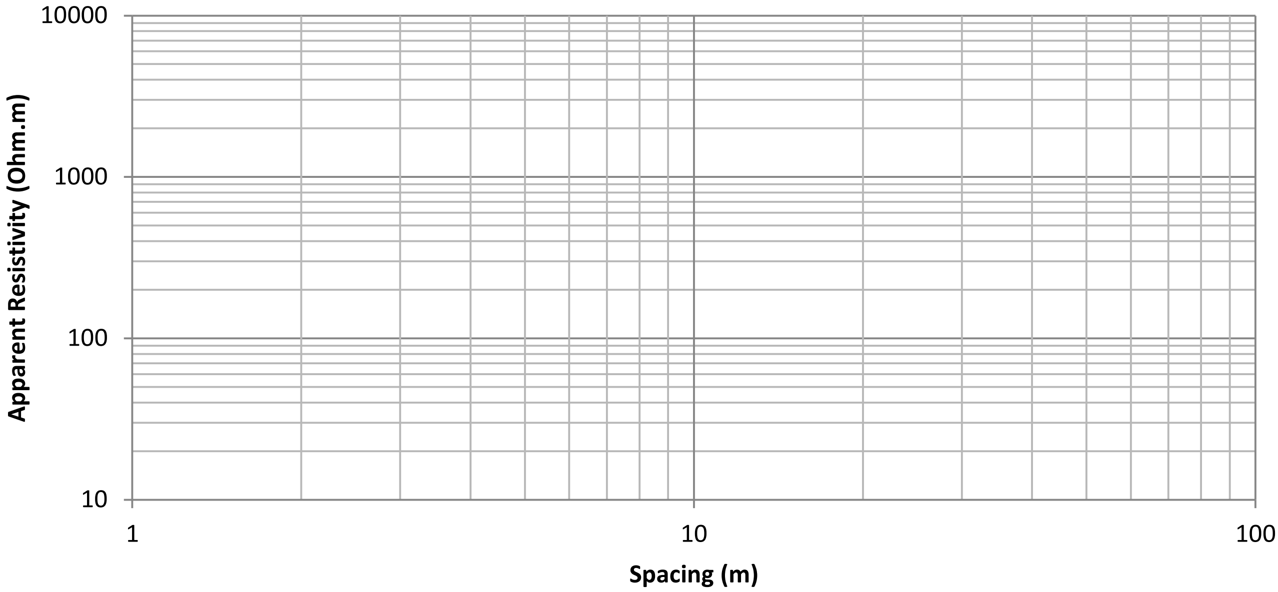
Test Unit Type: ______________ Serial Number: __________________ Last Calibrated: ___/___/___

Site Observations: ____

Soil Type (Rock, sand etc.): ____

Recent Rainfall: ____

Probe Spacing (a) (m)	Resistance Reading (R) (Ω)		Instrument Alarm? Y/N	Apparent Resistivity $\rho_a = 2\pi aR$ (Ωm)	Notes: (E.g. depth, watered etc.)
	CPPC	PCCP			
1					
2					
4					
8					
16					
20					



Annexure 7: Earth Resistance Test Sheet

FOP or ART Test Measurement Sheet

Project: ____ **Date:** ___/___/___

Job Site / Location: _________________________________**Time:**______________

Tested by: ____

Test Unit Type: ______________Serial Number: __________________ Last Calibrated: ___/___/___

Site Observations: ____

Soil Type (Rock, sand etc.): ____