Electricity Distribution

nationalgrid

Company Directive

STANDARD TECHNIQUE: TP21OB

Earthing System Measurements - Part B
Earth Electrode Resistance

Summary

This Standard Technique defines the requirements for carrying out earth electrode resistance measurements on earthing systems which are to be owned or adopted by National Grid Electricity Distribution.

Author: **Graham Brewster**

Implementation Date: **December 2022**

Approved by

Carl Ketley-Lowe
Engineering Policy Manager

Date: **1st December 2022**

Target Staff Group	**Network Services Teams, Engineering Trainers & ICPs**
Impact of Change	**AMBER - The changes have an impact of current working practices that are not safety critical – Communication at next team meeting or as part of a retraining programme**
Planned Assurance Checks	**Policy Assurance Specialists shall confirm whether the requirements have been complied with during their sample checking of completed jobs**

IMPLEMENTATION PLAN

Introduction
This Standard Technique defines the requirements for carrying out earth electrode resistance measurements on earthing systems which are to be owned or adopted by National Grid Electricity Distribution.

Main Changes
This document is a new ST, however, it replaces parts of TP21O.

This ST introduces additional techniques for measuring earth electrode resistance, including the use of clamp-on CTs and VTs in conjunction with four-terminal earth testers, and also clamp-on hand–held testers. It also includes additional information and guidance on earth electrode resistance measurement.

Impact of Changes
This Standard Technique is relevant to staff, Contractors and Independent Connection Providers involved with the design / assessment of earthing systems.

Implementation Actions
Managers should notify relevant staff that this Standard Technique has been published.

There are no retrospective actions.

Implementation Timetable
The document can be implemented once being read and understood and can be utilised from issue.

REVISION HISTORY

Document Revision & Review Table		
Date	**Comments**	**Author**
December 2022	TP21OB issued	Graham Brewster

Contents

1.0 INTRODUCTION

The main reasons for measuring the resistance of an earth electrode are:

- To ensure that a new installation has attained a value equal to, or less than, the design value
- To ensure that the resistance of an existing installation has not substantially changed from its original value unless by design.

The correct resistance value is necessary to ensure, in the event of an earth fault, that sufficient fault current flows to cause protection to reliably operate and that the earth potential rise (EPR) does not present a danger to staff or the general public.

There are a number of different test methods used to measure earth electrode resistance, which are based on a Fall of Potential (FOP) technique, namely:

- FOP Slope method
- FOP 62% method
- FOP 90°/180° method

However there are situations, typically in urban areas, where it is not practicable to measure the earth electrode resistance this way and alternative methods using ‘clamp-on’ techniques are available.

This Standard Technique defines the requirements for carrying out earth electrode resistance measurements on earthing systems which are to be owned or adopted by National Grid Electricity Distribution.

2.0 DEFINITIONS

For the purpose of this document the following definitions are employed:

TERM	DEFINITION
Earth Electrode	A conductor or group of conductors in direct contact with the soil and providing an electrical connection to earth.
Earthing Conductor	A protective conductor which connects plant and equipment to an earth electrode.
Earthing System	The complete interconnected assembly of earthing conductors and earth electrodes (including cables with un-insulated sheaths).
Earth Impedance	The impedance between the earthing system and remote reference earth.
Earth Potential	The difference in potential which may exist between a point on the ground and remote reference earth.

TERM	DEFINITION
Transfer Voltage	The potential transferred by a long metallic object which is connected to earth at one or more points and which bridges locations that are at different potentials with respect to the general mass of earth. As such, the object may transmit the potential rise of an earthing system into an area with low or no potential rise, or transmit reference earth into an area of potential rise, resulting in a potential difference occurring between the object and its surroundings.
Reference Earth	Part of the Earth, the electric potential of which is conventionally taken as zero.
Soil Resistivity	Electrical resistivity of a typical sample of soil

3.0 REFERENCES

This document makes reference to, or should be read in conjunction with, the documents listed below. The issue and date of the documents listed below shall be those applicable at the date of issue of this document, unless stated otherwise.

3.1 British Standards

NUMBER	TITLE
BS EN 50552	Earthing of power installations exceeding 1 kV a.c.

3.2 Energy Networks Association

NUMBER	TITLE
ENA TS 41-24	Guidelines for the design, installation, testing and maintenance of main earthing systems in substations

4.0 OVERVIEW OF ELECTRODE RESISTANCE MEASURMENT

There are several different methods for measuring earth electrode resistance, including the Fall-of-Potential method, Clamp Tester method, High Current Injection method, etc.

The former can be realised using either a three or four terminal earth tester. The Fall-of-Potential four terminal method is discussed in this document because it is the method mandated by National Grid Electricity Distribution.

There are situations, typically in urban areas, where it is not practicable to measure the earth electrode resistance using the Fall-of-Potential method. Also discussed in this document is the Clamp Tester method which National Grid Electricity Distribution permits use of in particular circumstances.

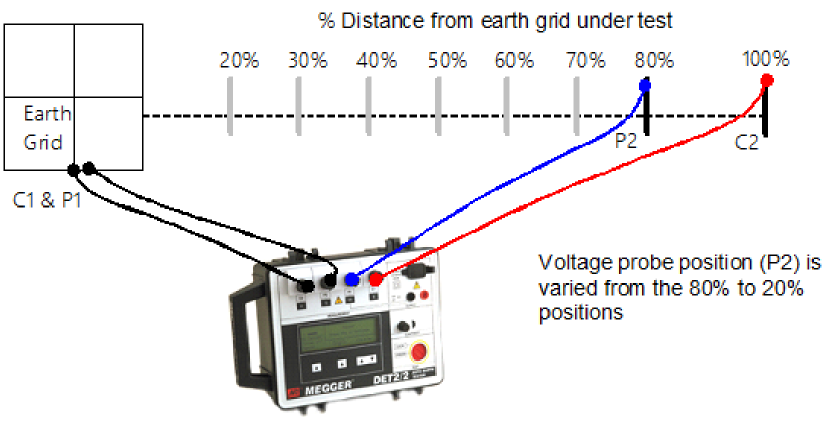
4.1 Resistance Measurement Using Fall-of-Potential Four-Terminal Method

An example of a four-terminal earth tester is shown in Figure 1 below.

Figure 1: Example of a four-terminal earth tester

The fall of potential test arrangement is shown in Figure 2 below.

Figure 2: Fall Of Potential test arrangement for 'Slope' or '62%' method



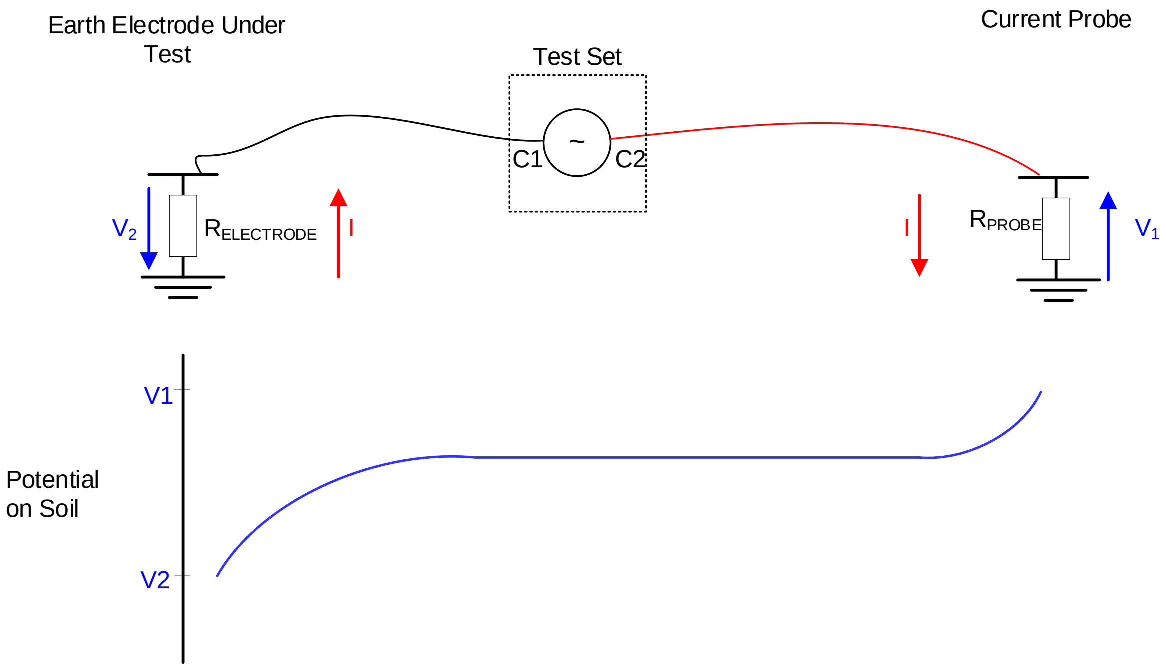
The test set C1 and P1 terminals are connected to the earth electrode system.

The current probe, which is connected to the C2 terminal on the test set, is placed as far as away as practicable from the earth electrode system to be measured. Ideally the distance from the earth electrode to the current probe should be at least six to ten times the maximum dimension across the diagonal of the earth electrode system.

The voltage probe, which is connected to the P2 terminal on the test set, is inserted, in a straight line between the current probe and the earth electrode system, at a number of positions in turn.

The test set circulates a current between the current probe and the earth grid which sets up a potential on the soil as shown in Figure 3 below. There is a 'zone of influence' in the vicinity of the electrode and the probe where the potential on the soil varies quite markedly with distance. Outside of these zones the potential on the soil remains fairly uniform with distance.

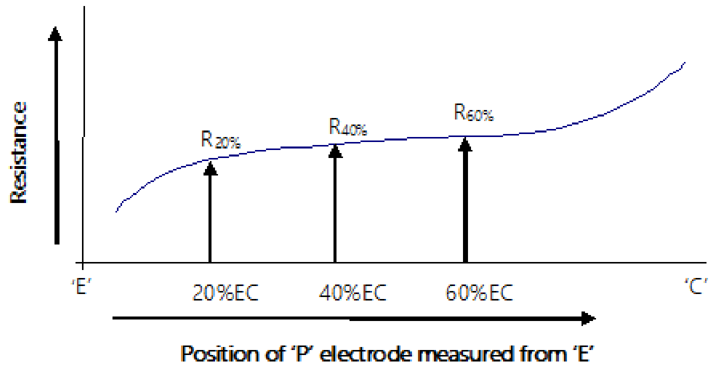
Figure 3: Potential on soil created by test set



The test set measures the potential difference between the voltage probe and the earth grid, from which it computes the resistance (since it also knows the magnitude of the current being circulated). The measured potential reduces (i.e. falls) as the voltage probe is moved towards the earth electrode, hence the 'fall-of-potential' name for the test.

The resistance is measured with the voltage probe in various positions and a resistance versus distance graph is plotted from the results, as shown in Figure 4 below. In this diagram the electrode position is 'E' and the current probe position is 'C'. Ideally, the resistance curve should have a relatively flat middle section (which corresponds to the relatively flat middle section of the potential on soil curve).

Figure 4: Typical resistance curve



If the earth electrode system is small (e.g. electrodes associated with poles and ground mounted distribution substations) and the soil has uniform resistivity then the resistance of the electrode is the value at the 62% position[1] i.e. 0.62EC.

In theory you could take a single measurement at the 62% position and use that as the electrode resistance. However, this 62% rule does not hold if the soil resistivity is not uniform or the remote current electrode is positioned too close to the electrode system. In these instances there is little or no flat middle section to the resistance curve (i.e. the resistance varies continually with distance). One way of validating the 62% value is by checking that the 57% and 67% resistance values are within ±2.5% of the 62% resistance value respectively.

The 62% rule also does not hold if the earth electrode system is large, for example, one associated with a grid or primary substation. For these sites, and also where the 57% and 67% resistance values lie outside the ±2.5% limit, an alternative approach, known as the slope method has to be employed.

The test arrangement is exactly the same as before i.e. as per Figure 2 above. Measurements are taken with the voltage probe in various positions and the resistance curve plotted as before. Referring to Figure 4 again, the apparent resistance values at the 20%. 40% and 60% positions are noted, namely $R_{20\%}$, $R_{40\%}$ and $R_{60\%}$, respectively. The 'slope coefficient' is calculated using the following formula:

$$Slope\ Coefficient = \frac{R_{60\%} - R_{40\%}}{R_{40\%} - R_{20\%}}$$

[1] Strictly speaking the resistance of the electrode is the value at the 61.8% position.

If the calculated slope coefficient is outside the range 0.40 to 1.60 then the current probe needs to be moved further away from the electrode and the test repeated. The percentage probe position is then read off the graph shown in Figure 5 or determined from the table shown in Figure 6.

Figure 5: Graph of probe position versus slope coefficient

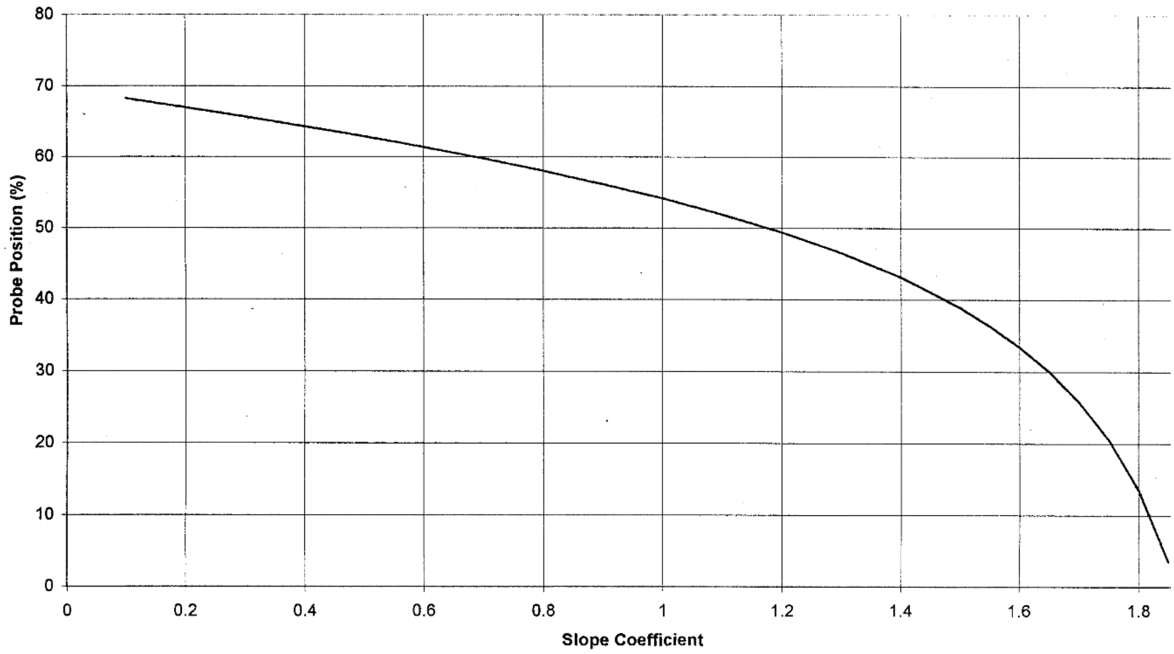


Figure 6: Table of probe position versus slope coefficient

Slope Coefficient	Probe Position	Slope Coefficient	Probe Position	Slope Coefficient	Probe Position
0.40	64.3%	0.80	58.0%	1.20	49.4%
0.41	64.2%	0.81	57.9%	1.21	49.1%
0.42	64.0%	0.82	57.7%	1.22	48.8%
0.43	63.9%	0.83	57.5%	1.23	48.6%
0.44	63.7%	0.84	57.3%	1.24	48.3%
0.45	63.6%	0.85	57.1%	1.25	48.0%
0.46	63.5%	0.86	56.9%	1.26	47.7%
0.47	63.3%	0.87	56.7%	1.27	47.4%
0.48	63.2%	0.88	56.6%	1.28	47.1%
0.49	63.0%	0.89	56.4%	1.29	46.8%
0.50	62.9%	0.90	56.2%	1.30	46.5%
0.51	62.7%	0.91	56.0%	1.31	46.2%
0.52	62.6%	0.92	55.8%	1.32	45.8%
0.53	62.4%	0.93	55.6%	1.33	45.5%
0.54	62.3%	0.94	55.4%	1.34	45.2%
0.55	62.1%	0.95	55.2%	1.35	44.8%
0.56	62.0%	0.96	55.0%	1.36	44.5%
0.57	61.8%	0.97	54.8%	1.37	44.1%
0.58	61.7%	0.98	54.6%	1.38	43.8%
0.59	61.5%	0.99	54.4%	1.39	43.4%
0.60	61.4%	1.00	54.2%	1.40	43.1%
0.61	61.2%	1.01	53.9%	1.41	42.7%
0.62	61.0%	1.02	53.7%	1.42	42.3%
0.63	60.9%	1.03	53.5%	1.43	41.8%
0.64	60.7%	1.04	53.3%	1.44	41.4%
0.65	60.6%	1.05	53.1%	1.45	41.0%
0.66	60.4%	1.06	52.8%	1.46	40.6%
0.67	60.2%	1.07	52.6%	1.47	40.1%
0.68	60.1%	1.08	52.4%	1.48	39.7%
0.69	59.9%	1.09	52.2%	1.49	39.3%
0.70	59.7%	1.10	51.9%	1.50	38.9%
0.71	59.6%	1.11	51.7%	1.51	38.4%
0.72	59.4%	1.12	51.4%	1.52	37.9%
0.73	59.2%	1.13	51.2%	1.53	37.4%
0.74	59.1%	1.14	50.9%	1.54	36.9%
0.75	58.9%	1.15	50.7%	1.55	36.4%
0.76	58.7%	1.16	50.4%	1.56	35.8%
0.77	58.5%	1.17	50.2%	1.57	35.2%
0.78	58.4%	1.18	49.9%	1.58	34.7%
0.79	58.2%	1.19	49.7%	1.59	34.1%

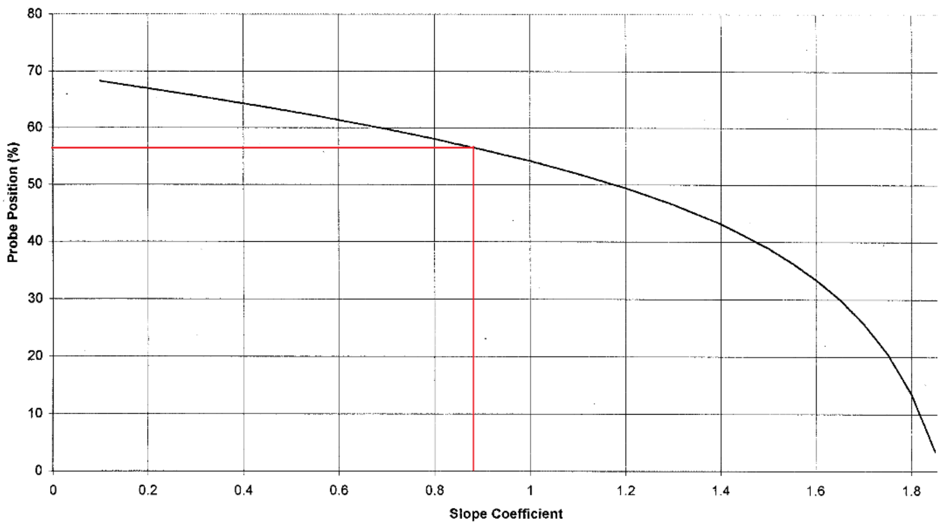
For example, assume the test results were as follows:

$R_{20\%} = 0.40$ ohm
$R_{40\%} = 0.48$ ohm
$R_{60\%} = 0.55$ ohm.

$$Slope\ Coefficient = \frac{0.55 - 0.48}{0.48 - 0.40} = 0.88$$

The percentage probe position is determined using the graph as shown in Figure 7. The value is 56%.

Figure 7: Determining percentage probe position using the graph



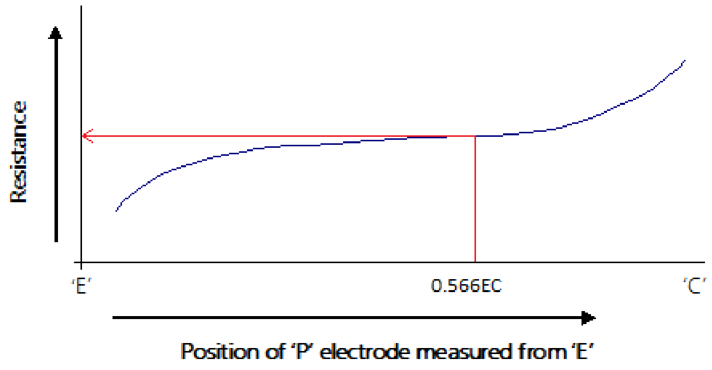
Alternatively, the probe position is determined using the tables as shown in Figure 8. The value is 56.6%.

Figure 8: Determining percentage probe position using tables

Slope Coefficient	Probe Position	Slope Coefficient	Probe Position	Slope Coefficient	Probe Position
0.40	64.3%	0.80	58.0%	1.20	49.4%
0.41	64.2%	0.81	57.9%	1.21	49.1%
0.42	64.0%	0.82	57.7%	1.22	48.8%
0.43	63.9%	0.83	57.5%	1.23	48.6%
0.44	63.7%	0.84	57.3%	1.24	48.3%
0.45	63.6%	0.85	57.1%	1.25	48.0%
0.46	63.5%	0.86	56.9%	1.26	47.7%
0.47	63.3%	0.87	56.7%	1.27	47.4%
0.48	63.2%	0.88	56.6%	1.28	47.1%
0.49	63.0%	0.89	56.4%	1.29	46.8%
0.50	62.9%	0.90	56.2%	1.30	46.5%

The earth electrode resistance is then determined from the resistance curve as shown in Figure 9.

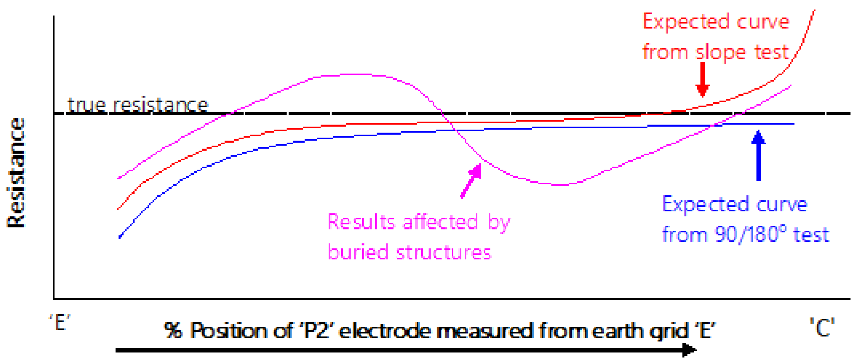
Figure 9: Determining electrode resistance from the resistance curve



The resistance curve should have a nice smooth inverted "S" shape, however, the presence of buried metal services or structures may distort or mis-shape the curve, as shown in Figure 10, or cause the slope coefficient to lie outside the range 0.40 to 1.60.

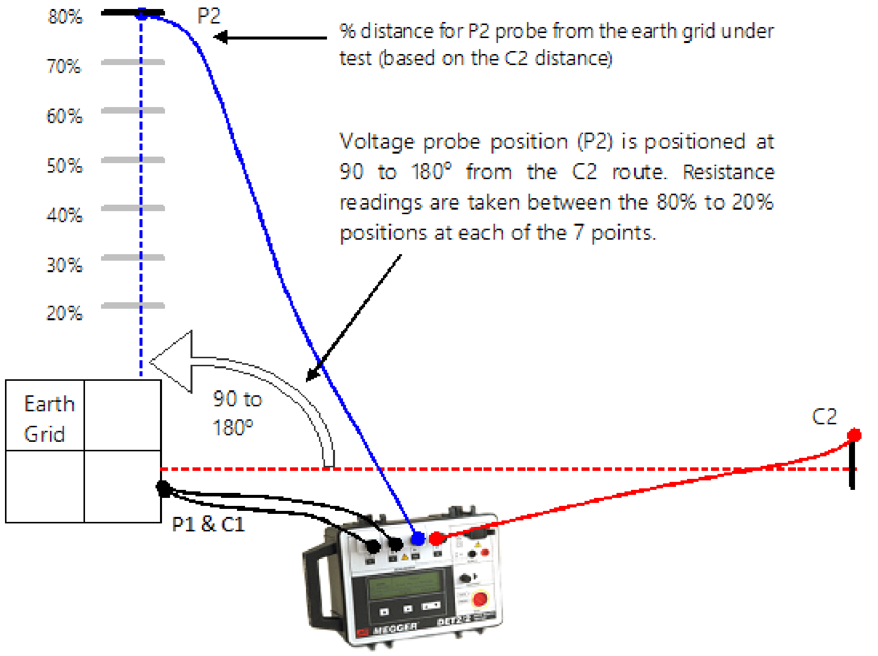
Where this situation arises, the fall-of-potential test should be repeated using a different direction of test route. If these alternative tests also fail then the Fall-Of-Potential 90°/180° test method should be tried.

Figure 10: Resistance curve when affected by buried metal services or structure



The Fall-Of-Potential 90°/180° test method is used in conjunction with the slope or 62% method to verify the results obtained. The current probe C2 is positioned as far as away from the earth electrode under test as is practicable, however, the voltage probe P2 is positioned at an angle between 90° and 180° to the current electrode route as shown in Figure 11.

Figure 11: Fall-Of-Potential 90° / 180° arrangement



Measurements are taken with the voltage probe in various positions and the resistance curve plotted as before. When the graph is drawn, it should level off, but never quite reach the true resistance value, as shown in Figure 10. By extrapolating (i.e. extending) the curve, the true resistance value can be estimated.

4.2 Resistance Measurement Using Fall-of-Potential Four-Terminal Method In Conjunction With A Clamp-On CT

Some earth resistance testers include a means of attaching a current transformer (CT). An example of a four-terminal earth tester and clamp-on CT is shown in Figure 12 below.

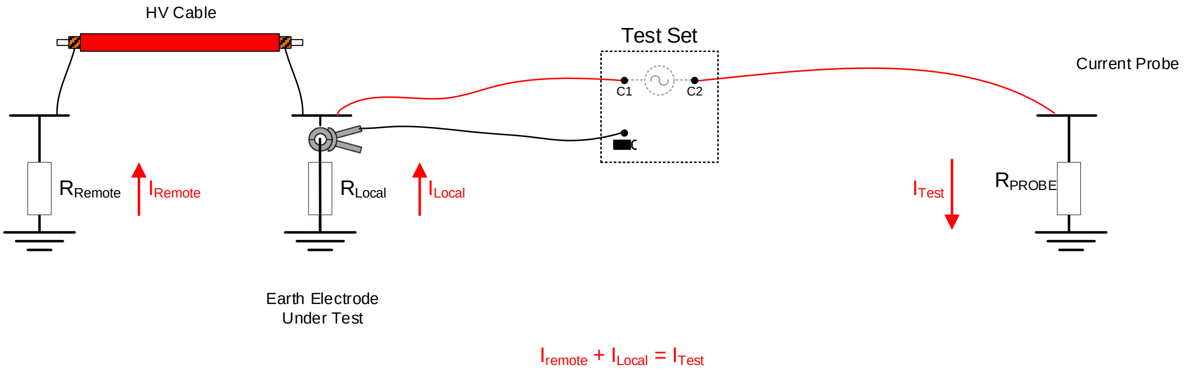
Figure 12: Example of a four-terminal earth tester and clamp-on CT

In some instances it is necessary to check the resistance value of a specific electrode which is connected to a larger earthing system.

For example, consider measuring the earth electrode resistance at a pole with a HV cable termination. The local and remote earth electrodes are connected in parallel via the cable sheath and consequently a standard test would provide an erroneous resistance value for the local electrode.

There are two ways of accurately measuring the resistance of the local earth electrode. The first way is to disconnect the local earth electrode from the cable sheath, however, this requires an outage on the associated HV circuit. The second way is to incorporate a current transformer (CT) into the test arrangement as shown in Figure 13 below (note: test set 'potential' connections omitted for clarity). The CT is clamped around the local earth electrode and it measures the portion of the test current returning via that specific electrode. This allows the resistance of the local earth electrode to be determined (using one of the standard FOP techniques described previously) without disconnecting it from the rest of the earth system. In other words, the resistance measurement can be carried out without an outage on the associated HV circuit.

Figure 13: Example test arrangement incorporating a CT



Other examples of where this technique may be advantageous includes (non-exhaustive list):

- Measurement of GMT HV electrode resistance without disconnecting HV cables and HV Customer earth bonds
- Measurement of PMT & GMT LV electrode resistance without disconnecting LV cables
- Measurement of high frequency earth electrode resistance at Grid or Primary substations

4.3 Resistance Measurement Using Clamp-On Method

4.3.1 Resistance Measurement Using A Four-Terminal Earth Resistance Tester In Conjunction With A Clamp-On CT And VT

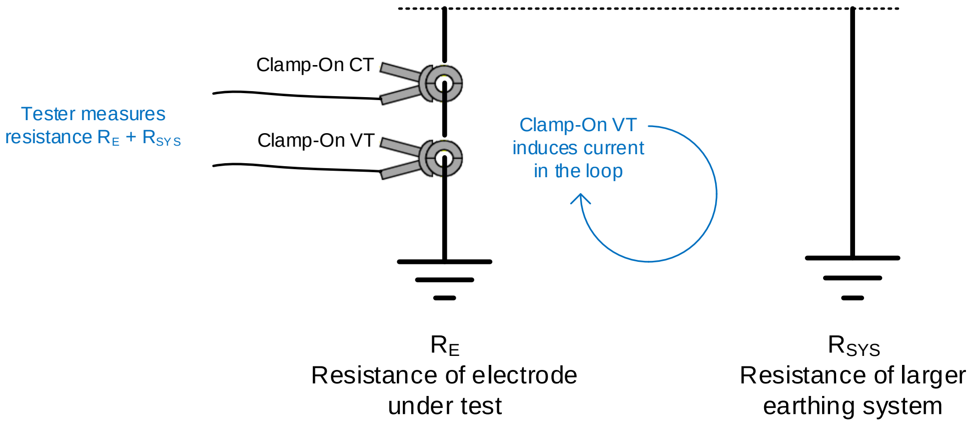
Some earth resistance testers include a means of attaching both a current transformer (CT) and a voltage transformer (VT). An example of a four-terminal earth tester and clamp-on CT and VT is shown in Figure 14 below.

Figure 14: Example of a four-terminal earth tester and clamp-on CT & VT

This method can be used where it is not practicable to measure the earth electrode resistance of a ground-mounted distribution substation using a fall-of-potential technique, for example, in an urban area where there is little or no green space available for laying out test leads and probes in the required way.

This technique depends on the electrode in question being connected to an earthing system with a much lower overall resistance than the electrode, as shown in Figure 15 below.

Figure 15: Test arrangement for clamp-on CT & VT



The clamp-on VT induces a voltage in the conductor of known magnitude. This voltage drives a current around the ‘loop’ which is directly proportional to the loop resistance. The clamp-on CT is used to measure this current and consequently the tester is able to compute the loop resistance from Ohm’s Law i.e. the resistance of the electrode under test plus the resistance of the larger earthing system. The measurement error is small if the resistance of the larger earthing system is much lower than that of electrode in question.

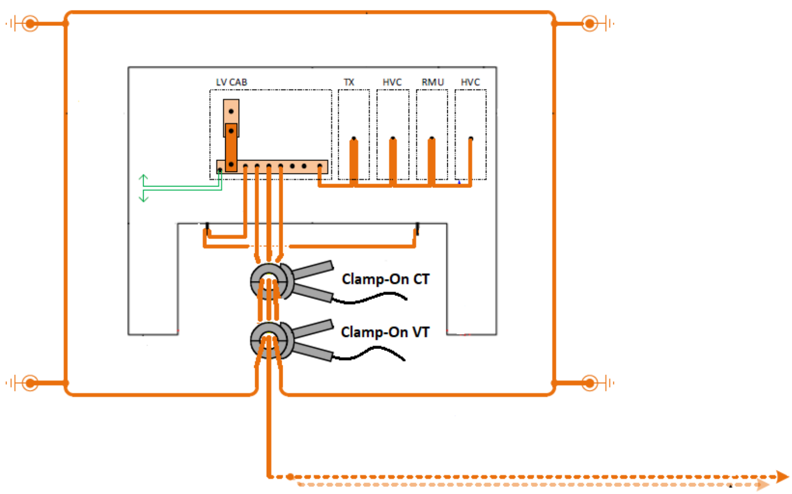
For example, if the electrode in question has an actual resistance of 10Ω and the larger earthing system had a resistance of 0.5Ω then the reading given by the tester would be 10.5Ω, which is sufficiently accurate (5% error). However, if the larger earthing system had a resistance of 5Ω then the reading would be 15Ω and hence unreliable (50% error).

In practice, the actual resistance of the larger earthing system is unlikely to be known and hence this technique is only suitable where there is confidence that the resistance of the larger earthing system is significantly less than that of the electrode under test.

It is apparent from Figure 15 that this technique cannot be used to measure the resistance of an isolated electrode because no alternative low resistance path exists to form the 'loop'.

Since this method determines an <u>approximate</u> resistance value for the earth electrode, it should only be employed where it is not practicable to use the fall-of-potential technique. An example of where this might be the case is a ground-mounted distribution substation located in a city or large town where there is little or no green space available. In other words, where the resistance of the electrode under test is much larger than electrode effect of the surrounding network i.e. network contribution to the electrode resistance. Figure 16 shows an example of how the resistance of a combined HV & LV earth electrode might be measured at such a substation.

Figure 16: Resistance measurement of a combined HV & LV electrode at an urban distribution substation



Individual electrodes such as capacitor VT and surge arrestor high frequency earths at a grid or primary substation can also be tested using this technique.

4.3.2 Resistance Measurement Using A Hand-Held Clamp-On Earth Resistance Tester

An example of a hand-held clamp-on earth resistance tester is shown in Figure 17 below.

Figure 17: Example of a clamp-on earth resistance tester

The hand-held earth resistance tester combines the CT and VT described in 4.3 above in a single clamp and has the same advantages and disadvantages.

5.0 REQUIREMENTS

5.1 132kV, 66kV and 33kV Substations

The fall-of-potential slope method shall always be utilised for measuring the electrode resistance of a 132kV, 66kV or 33kV substation.

5.2 Pole-Mounted and Ground-Mounted Distribution Substations

The fall-of-potential 62% method shall be utilised for measuring the electrode resistance at pole-mounted and ground-mounted distribution substations.

The fall-of-potential slope method may be employed when the 62% method has been tried and the 57% & 67% values fall outside the permitted tolerance band.

The fall-of-potential 90°/180° method may be employed to verify the results from the 62% and slope methods when there is a concern those results may have been influenced by buried metallic structures.

5.3 Poles, Towers and Ground-Level Cable Sealing End Compounds

The fall-of-potential 62% method shall be utilised for measuring the electrode resistance at a pole, tower or ground-level sealing end compound.

The fall-of-potential slope method may be employed when the 62% method has been tried and the 57% & 67% values fall outside the permitted tolerance band.

The fall-of-potential 90°/180° method may be employed to verify the results from the 62% and slope methods when there is a concern those results may have been influenced by buried metallic structures.

5.4 Other Small Electrode Systems

Other small electrode systems include (non-exhaustive list):

- PME electrodes bonded to the LV network
- Customer earth electrode bonded to the NGED main earth terminal

Hand-held clamp-on earth resistance testers may be employed to measure the resistance of these small electrode systems where they are bonded to a larger earthing system which has a significantly lower earth resistance than the electrode under test, and where approximate results are acceptable.

Where this is not the case, the fall-of-potential 62% method shall be utilised for measuring the electrode resistance.

5.5 Sources Of Measurement Error

Paint, scale or oxide coatings on conductors may affect the accuracy of the resistance measurement. Conductors shall be abraded to expose clean surfaces for connections.

High contact resistance on the current and voltage probes may also affect the accuracy of the resistance measurement. Probes shall be pushed in deep enough to ensure low contact resistance. If necessary, saline solution shall be poured onto the probes.

If the measured resistance value is varying significantly this may be due to interference, high contact resistance on the current and potential probes, damaged test leads or the resistance measurement is at the lower limit of the instrument's capability. Improvement may be obtained by choosing a different test route, employing earth tester internal filters, varying the frequency of the test current, re-installing current and potential probes, pouring saline solution into the hole made by the probes, or increasing current injected. If, despite this, the reading continues to vary by more than 5%, a series of 10 consecutive measurements shall be taken and the average values used.

Care is required to ensure leads are correctly connected. Common errors include having voltage and current leads swapped, or having the voltage lead disconnected. In both cases a resistance measurement will be generated, but it will be erroneous.

5.6 Test Results

The following spreadsheet shall be employed for recording the results of a Fall-of-Potential test. The spreadsheet automatically calculates the electrode resistance from the test results and also allows the results to be sent to a printer or pdf document.

TP21OB Test Results

6.0 RISK ASSESSMENT AND METHOD STATEMENT

6.1 Risk Assessment

HAZARD	PROBABILITY	CONTROL MEASURES
Electric shock or burns as a result of earth potential rise	Low	• No testing if lightning is likely • No testing whilst fault switching is being undertaken • No testing if insulators are damaged • Use of insulated mats, gloves and footwear
Electric shock or burns from test voltages / currents	Low	• One person in control of testing • Radio communication between earth tester operator and personnel who move remote current and voltage probes (who may be out of sight / earshot)
Electric shock or burns from induced voltages from nearby power lines	Low	• Avoid test probe route parallel with overhead lines, if possible • If not possible, maximize separation between test probe route and overhead line
Electric shock or burns due to damaged test equipment or leads	Low	• Ensure condition of test equipment and leads are satisfactory prior to use
Slips, trips and falls	Medium	• Maintain awareness of surroundings whilst undertaking measurements
Members of public or livestock tripping over or getting tangled up in test leads	Medium	• Maintain awareness of surroundings whilst undertaking measurements
Traffic hazards if working adjacent to the highway	Medium	• Use appropriate road safety equipment and signing where necessary • Wear high-visibility workwear • Maintain awareness of surroundings whilst undertaking measurements
Driving probes into buried services	Low	• Check for presence of buried services using utility company records.

6.2 Method Statement

6.2.1 Equipment

The following test equipment is required in order to measure the resistance of an earth electrode:

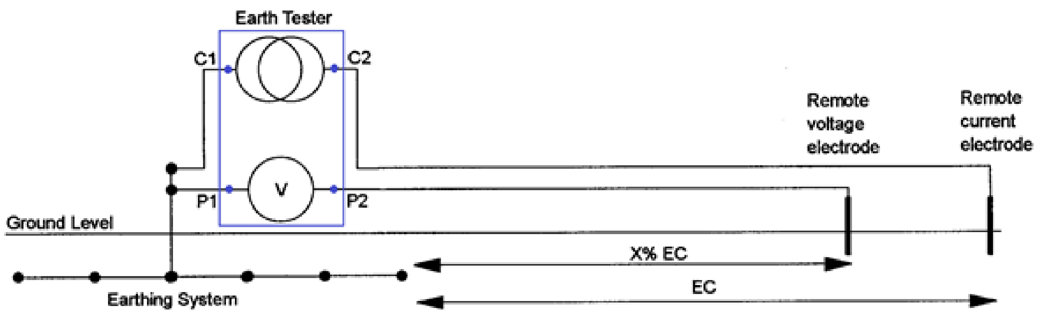
- High-resolution four-terminal earth tester (e.g. Megger DET2 or Megger DET4TC)

- Clamp-on CT (where relevant)
- Insulated test leads[2] (mounted on cable drums for ease of use) – minimum 1.5mm^2
- Earth probes and earth probe connectors x2
- Insulating rubber mat
- Aluminium alloy or copper earth mat
- Lead for connection of earth mat to earthing system
- Club hammer
- Radio transceiver x2
- Paint scraper, emery cloth and wire brush
- Class 1 rubber gloves
- Insulating safety footwear
- Road safety signs etc. (where relevant)
- High-visibility workwear (where relevant)

6.2.2 Test Arrangement

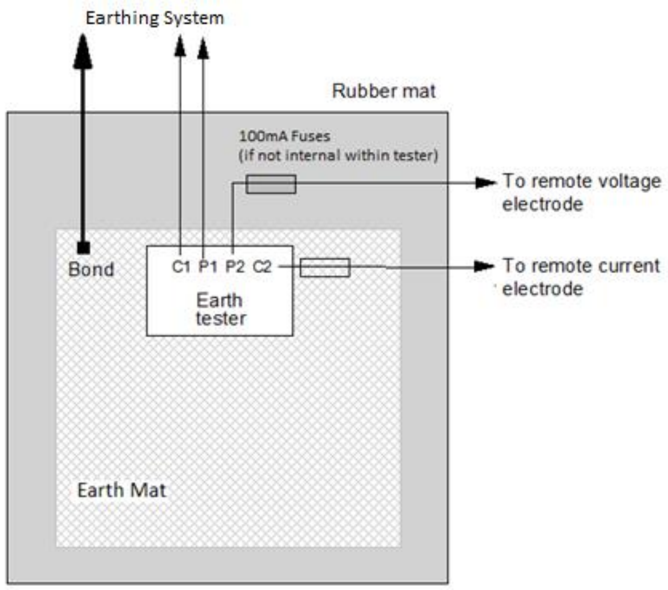
Figure 18 and Figure 19 shows the test arrangement to be employed for measuring the electrode resistance.

Figure 18: Electrode resistance measurement arrangement



[2] For ease of identification it is recommended that the remote current and voltage leads are different colours; standardize on red = current, green = voltage.

Figure 19: Test position detail (external fuses optional)



6.2.3 Safety Precautions

The following precautions shall be taken when measuring the electrode resistance of an earthing system:

- Comply with applicable safety rules.
- Conduct Site Specific Risk Assessment and communicate risks to people at risk in accordance with ST: HS20A. See also Section 6.1 above.
- All testing under immediate control of one person.
- Communication between earth tester operator and personnel who move remote probes.
- Personnel to wear Class 1 rubber gloves and the additional protection of insulating safety footwear.
- In the case of 132kV, 66kV or 33kV substations the earth tester position shall be at the approximate middle of the earth electrode system.
- Insulating rubber mat at earth tester position.
- Earth mat placed on top of insulating rubber mat and connected to electrode under test.
- Operator stands with both feet on earth mat during period of test.
- Avoid test probe route parallel with overhead line, if possible.
- If route is parallel to overhead line(s), a minimum separation of 20m is preferable.
- Avoid driving test probes into buried services.
- No testing if lightning likely (e.g. lightning risk warning Category 1).

- CONTROL notified and no work if relevant fault switching planned/under way.
- If relevant lightning or fault switching occurs while testing, the testing must cease immediately.
- Use appropriate road safety equipment and signing where appropriate. See ST: HS14D.
- Ensure condition of test equipment is satisfactory prior to use.

6.2.4 Method

1	DETERMINE	the distance EC to the remote current probe from the edge of the earth electrode. In the case of 132kV, 66kV and 33kV substations this should ideally be 6 to 10 times the length of the substations' longest diagonal i.e. typically 600m or more. In the case of pole & ground mounted distribution substations and poles and towers this should ideally be 100m or more. In the case of rods then normally 30m should suffice.
2	IDENTIFY	possible test route. Ideally, this should be across undisturbed soil, avoiding road crossings and at right angles to overhead lines and buried conductor. Landowner permission shall be obtained where necessary.
3	CHECK	for presence of buried conductor/cable/pipe using utility company records and above-ground detection equipment. Modify proposed route to cross at right angles if possible.
4	CHECK	phase conductor insulators on HV apparatus connected to the earthing system are undamaged. If damage is found, no testing shall be carried out until the defective HV apparatus has been made dead.
5	INFORM	Control before commencing work. Confirm risk of lightning not Category 1 and that no fault switching will be performed.
6	PLACE	insulating rubber mat on the ground at the test position and place the earth mat on top. Connect earth mat electrically to the earthing conductor to be tested, cleaning conductor if necessary. Place earth tester on earth mat. Connect C1 and P1 terminals to earthing conductor. The test arrangement is shown in Figure 19.

7	DETERMINE	The distance to the remote voltage probe when positioned at 80%, 70%, 67%, 62%, 60%, 57%, 50%, 40%, 30% and 20% of EC. These distances are computed automatically when using the ‘Test Results’ spreadsheet.
8	PLACE	the two cable drums at the edge of the electrode to be tested. For ease of identification it is recommended that the current and voltage leads are different colours e.g. red = current and green = voltage. Pull off sufficient length to reach the earth tester position. Secure the leads so they don’t move as you unroll the cables. Walk to 80% of EC unrolling both the cables and insert the remote voltage probe. Continue on to EC unrolling just the current cable and insert the remote current probe. Push current probe in deep to ensure low contact resistance as this allow the earth tester to inject more current.
9	CONNECT	the leads to their remote probes and confirm personnel 'standing clear'.
10	CONNECT	the trailing lead from the remote current probe to C2 and the trailing lead from the remote voltage probe to P2. The test arrangement is shown in Figure 18. Note: Care is required to ensure leads are correctly connected. Common errors include having voltage and current leads swapped, or having the voltage lead disconnected. In both cases a resistance measurement will be generated, but it will be erroneous.

11	SWITCH	the earth tester on and, after 30s, record the resistance in the 'Test Results' spreadsheet. If the value is varying significantly this may be due to interference, high contact resistance at the earth probe, damaged test lead or measurement at lower limit of instrument capability. Improvement may be obtained by employing earth tester internal filters, variation of the test current frequency, re-installing earth probes, pouring saline solution into the hole made by earth rod or increasing current injected. Note: switch the earth tester off, disconnect the C2 & P2 leads and place them on the insulated rubber mat (not on the metal earth mat) prior to adjusting the earth probes. Only re-connect C2 & P2 leads once personnel confirmed 'standing clear' of the remote probes. If the reading is varying by more than 5%, take a series of 10 consecutive measurements and record the average.
12	SWITCH	the earth tester off, disconnect the P2 lead placing it on the insulated rubber mat (not on the metal earth mat) and request 'move voltage probe'.
13	REPOSITION	voltage probe and repeat Stages 9 to 12 inclusive until measurements have been completed with the voltage probe at 70%, 67%, 62%, 60%, 57%, 50%, 40%, 30% and 20% of EC.
14	PLOT	measured resistance against voltage probe position as a percentage of EC. This plot is generated automatically when using the 'Test Results' spreadsheet. Examine the plot for evidence of rogue readings or buried structures influencing the results – see Figure 10 for guidance. Repeat individual measurements or the whole set using a different test route or with the remote current probe placed further away as is necessary.
15	DETERMINE	the earth electrode resistance. The resistance value is computed automatically when using the 'Test Results' spreadsheet.

APPENDIX A SUPERSEDED DOCUMENTATION

None

APPENDIX B RECORD OF COMMENT DURING CONSULTATION

No comments received

APPENDIX C ANCILLARY DOCUMENTATION

POL: TP21 - Fixed Earthing Systems

APPENDIX D KEY WORDS

Earth; Earthing; Electrode; Measurement; Test; Resistance; FOP; Potential