Electricity Distribution

nationalgrid

Company Directive

STANDARD TECHNIQUE: TP21OA

Earthing System Measurements - Part A
Soil Resistivity

Summary

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

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Implementation Date: **December 2022**

Approved by

Carl Ketley-Lowe
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Date: **1st December 2022**

Target Staff Group	**Network Services Teams, Engineering Trainers & ICPs**
Impact of Change	**GREEN - The change has no immediate impact on working practices or has been aligned to current working practices – Communication via a monthly update of changed policy. Team Manager discretion on how the changes are communicated to the team.**
Planned Assurance Checks	**Policy Assurance Specialists shall confirm whether the requirements have been complied with during their sample checking of completed jobs**

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IMPLEMENTATION PLAN

Introduction

This Standard Technique defines the requirements for carrying out soil resistivity measurements for 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 information and guidance on soil resistivity 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	TP21OA issued	Graham Brewster

Contents

1.0 INTRODUCTION

The resistance to earth of an earth electrode depends on the soil resistivity as well as on the dimensions and arrangement of the conductors in direct contact with the soil.

Soil resistivity varies considerably from location to location as a result of changes to the type of soil, grain size, density and moisture content. Furthermore, soil resistivity can vary considerably with depth because of the presence of distinct layers of soil with differing properties.

Accordingly, earthing system design requires an understanding of the soil resistivity and how it varies with depth at the electrode location. Soil resistivity values should ideally be obtained by measurement on site.

This Standard Technique defines the requirements for carrying out on-site soil resistivity measurements for 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 Potential	The difference in potential which may exist between a point on the ground and remote reference earth.
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
CDEGS	Current Distribution Electromagnetic Interference Grounding and Soil Structure Analysis. A set of integrated software tool produced by Safe Engineering Services & Technologies Ltd.
RESAP	A tool for analysing soil resistivity incorporated within CDEGS.

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 ac

3.2 Energy Networks Association

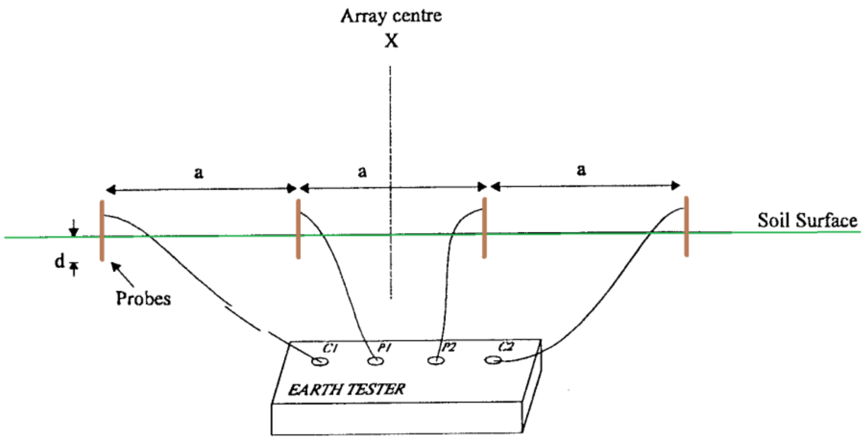
NUMBER	TITLE
ENA TS 41-24	Guidelines for the design, installation, testing and maintenance of main earthing systems in substations

4.0 OVERVIEW OF SOIL RESITIVITY MEASUREMENT

There are several different methods for determining soil resistivity, including Wenner method (equally spaced probes), Schlumberger method (unequally spaced probes) and the driven rod method. The Wenner method is discussed in this document because it is the most commonly used and it is also the method mandated by National Grid Electricity Distribution.

The Wenner method employs a four-terminal earth tester and four probes, which are placed in a straight line at equal distances 'a' apart and pushed into the ground to a depth 'd' as shown in Figure 1.

Figure 1: Soil Resistivity Test Arrangement



Current is passed through the two outer probes and the potential is measured between the two inner probes, from which resistance can be determined by Ohm’s law. The resistivity of the soil can then be computed using the formula

$$\rho = 2 \times \pi \times a \times R$$

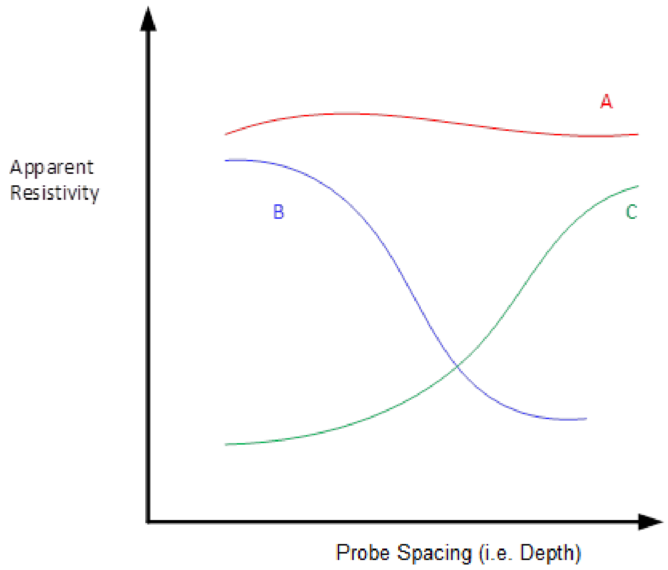
Where

ρ = soil resistivity (Ωm)
a = distance between the probes (m)
R = resistance value measured by earth tester

The test essentially determines the soil resistivity at a depth equal to the probe spacing i.e. when the probes are separated by 4.5m the soil resistivity at a depth of 4.5m is ascertained. Therefore, a series of measurements taken at different probe spacings allows a plot of resistivity versus probe spacing to be produced, which is effectively a plot of soil resistivity versus depth.

Figure 2 shows some example soil resistivity plots. A graph like ‘A’ indicates the soil resistivity doesn’t vary much with depth i.e. uniform soil. A graph like ‘B’ indicates that the soil resistivity reduces with depth i.e. high resistivity soil over low resistivity soil. A graph like ‘C’ indicates that the soil resistivity increases with depth i.e. low resistivity soil over high resistivity soil.

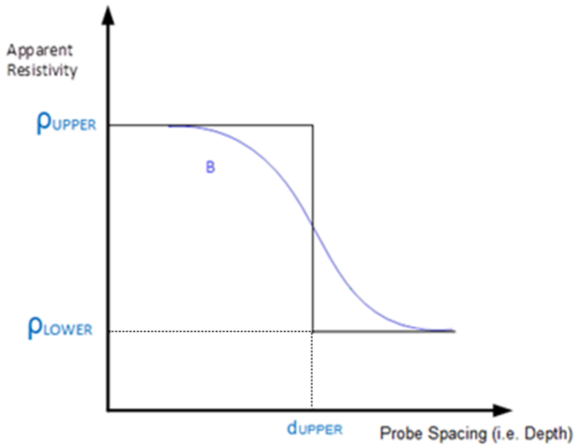
Figure 2: Example soil resistivity plots



The plots show that soil resistivity varies continually with depth in a non-linear manner. Unfortunately this reality is too difficult to accommodate within earthing-related calculations, even if they are computer-based, and so normal practice is to generate an equivalent soil model which assumes the soil is made up of a number of layers, with each layer having uniform resistivity. The equivalent soil model may have 1, 2, 3 or more layers as is necessary for it to accurately track the soil resistivity plot.

For example, consider a soil resistivity plot similar to ‘B’ in Figure 2 above. For earthing calculations the equivalent soil model is assumed to have two layers, with the top layer having resistivity ρ_{UPPER} and depth d_{UPPER} and the bottom soil layer having resistivity ρ_{LOWER} and infinite depth as shown in Figure 3.

Figure 3: Equivalent two-layer soil-model for soil resistivity plot 'B'



5.0 REQUIREMENTS

5.1 Method

Soil resistivity shall be measured using the Wenner method and a four-terminal earth tester in order that its variation with depth can be determined. Figure 1 shows the test arrangement.

The four probes shall be placed in a straight line at equal distances 'a' apart and pushed into the ground to a depth 'd', as shown in Table 1.

Table 1: Probe spacing and depth

Spacing 'a' (m)	Probe Depth 'd' (cm)
1	5
1.5	5
2	5
3	10
4.5	10
6	10
9	15
13.5	15
18	15
27	20
36	20
54	20

The minimum permissible range of probe spacings to be employed depends on the type of earth electrode and is shown in Table 2.

Table 2: Minimum permissible range of probe spacings

Earth Electrode Type	Minimum Range of Probe Spacings
Pole	1m to 13.5m
Ground-mounted distribution substation	1m to 18m
Tower	1m to 27m
66kV or 33kV substation	1m to 36m
132kV substation	1m to 54m

The soil resistivity shall be calculated for each probe spacing using the formula:

$$\rho = 2 \times \pi \times a \times R$$

Where

ρ = soil resistivity (Ωm)
a = distance between the probes (m)
R = resistance value measured by earth tester

A plot of soil resistivity versus probe spacing shall be produced on a graph utilising logarithmic scales on both horizontal and vertical axes.

Where at all possible the soil resistivity shall be measured at the actual location of the proposed earth electrode.

Where there is insufficient space available to achieve the minimum permissible range of probe spacings, the soil resistivity shall be measured at a location as close as possible to the proposed electrode position, for example, in a nearby field or park or other open space.

The test location shall be carefully selected in order to avoid being influenced by buried metallic objects (such as cables with hessian or jute serving, earth electrodes, pipes, etc), for example, by consulting utility company records. Measurements taken above or near buried metallic objects will suggest lower resistivity values than actually exist.

At least two sets soil resistivity measurements shall be taken, using a different orientation of the four probe array in each case (ideally at a 90° angle to each other), in order that that anomalous results can be identified by comparison with unaffected results. Anomalous results may occur due to high contact resistance on a probe, the influence of unknown buried metallic objects, or by interference from stray voltages in the soil or induction from nearby electrical systems.

5.2 Sources Of Measurement Error

High contact resistance on the current and voltage probes may affect the accuracy of the resistance measurement. Probes shall be pushed in deep enough to ensure low contact resistance but without exceeding a depth greater than one-twentieth of the probe spacing (i.e. $d \leq 0.05 \times a$). 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. A common error is having voltage and current leads swapped - a resistance measurement will be generated, but it will be erroneous.

5.3 Interpretation Of Results

For 132kV, 66kV and 33kV substations, interpretation of the apparent soil resistivity results shall be undertaken using CDEGS RESAP software in order to derive a representative multi-layer soil model for the site.

Whilst it is preferable for the same approach to be used for other types of earth electrode, this is usually not reasonably practicable unless an earthing consultant / specialist has been employed to carry out the earthing design. In these instances, interpretation of the apparent soil resistivity results shall be by inspection[1] using the following methodology in order to derive a two-layer soil model for the site:

- The upper soil layer shall be assumed to have a depth of 3m
- The resistivity of the upper soil layer shall be the average resistivity for the probe spacings in the range 3m or less
- The resistivity of the lower soil layer shall be the average resistivity for the probe spacings in the range greater than 3m

5.4 Test Results

The following spreadsheet shall be employed for recording the results of a soil resistivity test. From the test results the spreadsheet automatically calculates the soil resistivity at a depth equal to the probe spacing and automatically generates a plot of soil resistivity versus depth. It also allows the results to be sent to a printer or pdf document.

TP21OA Test Results

[1] The interpretation of measurement results by inspection is less precise than using formulae and/or software tools employing curve-fitting techniques, however, this approach is usually sufficiently accurate for the type of earth electrode in question.

6.0 RISK ASSESSMENT & METHOD STATEMENT

6.1 Risk Assessment

HAZARD	PROBABILITY	CONTROL MEASURES
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 perform soil resistivity measurements:

- High-resolution four-terminal earth tester (e.g. Megger DET2 or Megger DET4TC)
- Insulated test leads (mounted on cable drums for ease of use) – minimum 1.5mm^2
- Earth probes and earth probe connectors x4
- Club hammer
- Radio transceiver x2

- Road safety signs etc. (where relevant)
- High-visibility workwear (where relevant)

6.2.2 Test Arrangement

Figure 1 shows the test arrangement to be employed for measuring the soil resistivity.

6.2.3 Safety Precautions

When performing soil resistivity measurements, the following precautions shall be taken:

- 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.
- Avoid test probe route parallel with overhead line if possible.
- If route is parallel, a minimum separation of 20m is preferable.
- Avoid driving rods into buried services.
- Use appropriate road safety equipment and signing (where relevant). See ST: HS14D.
- Wear high-visibility workwear (where relevant)
- Ensure condition of test equipment is satisfactory prior to use.

6.2.4 Method

1	DETERMINE	the minimum permissible range of probe spacings from Table 2 above.
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	PUSH	the four earth rods into the ground in a straight line at equal distances 'a' metres apart and to a depth of 'd' centimetres as shown in Table 1.
5	CONNECT	the leads to their remote probes and confirm personnel 'standing clear'.
6	CONNECT	the trailing leads from the remote current probes (the outer two probes) to earth tester terminals C1 and C2 and the trailing leads from the remote potential probes (the inner two probes) to earth tester terminals P1 and P2, as shown in Figure 1. Note: Care is required to ensure leads are correctly connected. A common error is having voltage and current leads swapped - a resistance measurement will be generated, but it will be erroneous.
7	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 probes, 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 onto the earth probes or increasing current injected. Note: switch the earth tester off and disconnect the test leads prior to adjusting the earth probes. Only re-connect test 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.
8	SWITCH	the earth tester off, disconnect the test leads and request 'move probes'.
9	REPOSITION	the earth probes and repeat Stages 4 to 8 inclusive until all the necessary probe spacings have been completed.
10	CALCULATE	the apparent soil resistivity using the formula $\rho = 2 \times \pi \times a \times R$. This is done automatically when using the 'Test Results' spreadsheet

11	PLOT	apparent soil resistivity against probe spacing. 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. Repeat individual measurements or the whole set using a different test route, as is necessary.
12	REPEAT	stages 1 to 11 above for a second test route, ideally perpendicular to the first.
13	DETERMINE	the equivalent soil model which accurately tracks the soil resistivity plot. In the case of 132kV, 66kV & 33kV substations this shall be undertaken using CDEGS RESAP software. In all other cases this shall be done by inspection, using the methodology described in Section 5.3 above.

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; Soil; Resistivity; Measurement; Test; Wenner