

Earthing Manual

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Revision Log For Earthing Manual

Changes made in version 1 February 2001		
	Title	Notes about the change
Documents Removed		
New Documents	Earthing Manual	New manual introduced.
Amended Documents	O/H Line & S/S manuals	Earthing sections in O/H Line & S/S manuals deleted and sign posted to the Earthing Manual

Earthing Manual – Summary of Changes to Jan 2002 Release

Manual	Section	Changes
E3 Soil Resistivity Measurements	2	One rod method – table for 1.2m rod included
	5	Urban networks – ‘Global Earthing System’ section added
E4 Earth Electrode Resistance Test	2.1.2	Explanatory note on fall of potential method added
	3	Hot zone 430 volt contour – measurement on site – new section added
E5 Distribution Standard Earthing Layouts	9.2	Assumptions explained: Urban networks – ‘Global Earthing System’ Number of rods Deep earths HV/LV separation distances
	11	Requirement to bond the LV cable to the LV neutral earth electrode introduced Explanatory notes about assumptions added
	12	Bottle ends and joints within the hot zone – warning against fitting the PME earth electrode
E6 Protective Multiple Earthing	1.11	European Naming of Earthing Systems – additional section
	3.2.19	Cell Phone Base Stations on 132, 275 or 400 kV Towers – additional section
	3.2.21	Multiple Services to Steel Framed Buildings – restriction on the use of PME - additional section
	FIG.11.	Supplies to Equipment Mounted on Electricity Towers and Communication Masts – Superseded by ER G78

E7 Earth Specification Overhead Network	Section 7.1.8	Separate earthing of 33kV XLPE cable support channels
	Section 7.2.2	Guidance on transferred potential with regard to metal fences clarified.

Section E1

General Information

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Revision Log For Section E1 General Information

Changes made in version 1	
Section	Notes about the change
E1	First Issue

1. INTRODUCTION

There have been few changes to Electricity supply industry earthing standards and practices since the introduction of Protective Multiple Earthing in the 1970's.

However, the widespread introduction of electronic equipment used in conjunction with telephone lines (i.e. fax machines, computer modems etc.) has highlighted the issue of Equipment Potential Rise and Transferred Potentials.

There have been incidents of damage to electronic during supply system earth faults and also transfers of potential into telecommunications systems. This has been of increasing concern to the European telecommunications industry over the danger to their equipment and staff from transferred potentials.

The problem has been further exacerbated by the use of insulated sheath cables (Alpex, PIAS etc). This means that we rely more and more on substation earth nests instead of the lead cable sheaths that traditionally provided much of our earthing system. A further factor is that the reduction in size of distribution plant enables us to build substations on smaller plots which are more difficult to earth.

The result is that the European telecommunications industry has driven through changes to earthing standards that now place onerous duties on the electricity supply industries to protect persons from electric shock due to Equipment Potential Rise, Touch, Transferred & Step Potentials.

This legislation is risk assessment based. The effects of electricity on persons varies between people depending on such things as their age, state of health, type of footwear etc, Also the effectiveness of earthing system varies according to soil types, weather conditions etc. It is incumbent on individual electricity companies to design, install and maintain their systems such that they satisfy the objectives set by of legislation.

This section of the Earthing Manual highlights the main changes now incorporated into East Midland Electricity standards in order to fulfil our obligations.

2. WHAT HAS CHANGED

The most major change is the classification of sites as 'Hot' or 'Cold'.

The threshold voltages have been selected according to a voltage / time criteria that is deemed to be safe for the majority of the population. Installations whose EPR exceed these limits are classified as hot and special precautions have to be taken the prevent danger.

132kV : 650V

33kV : 650V (high reliability lines with main protection which operates within 0.2 seconds and has back up protection).

33kV : 430V (low reliability lines or clearance times in excess of 0.2 sec).

11kV : 430V

2.1 Combined /Segregated HV/LV Earths

The most obvious precaution is that we segregate the HV and LV earths to prevent HV earth fault potentials being transferred into premises via the LV neutral/earth.

This in itself is nothing new, pole transformers have often had separate HV/LV earths. Also we used to deem it acceptable to combine HV and LV earths when their combined resistance was less than 1 ohm. **This has now changed.**

- A 1 ohm resistance could result in an EPR of up to 2kV. This used to be deemed acceptable as domestic appliances were flash tested to 2kV. **This is no longer acceptable**
- To achieve an EPR less than 430 volts we need an earth less than 0.2 Ohms. Not only is this impractical to achieve at a distribution substation or pole transformer earth nest it is also impossible to measure with standard earth testing equipment.

Furthermore we used to separate the LV & HV earths by 3 metres to avoid transferring potential via the ground. **This is no longer acceptable.** We now have to place the LV earth system outside of the 430 volt potential contour that surrounds the installation during an earth fault. This distance changes depending in the local earth resistivity and the size of the HV earth nest. In very high resistivity soils this can be over 50 metres.

These separation distances have been calculated by a earth modelling computer programme and they are listed in Section “E5 Distribution Standard Earthing Layouts”.

2.2 When is an installation ‘Hot’ or ‘Cold’ ?

It is impractical to measure earth resistances down to 0.2 Ohms.

When we design a Grid or Primary Substation the EPR can be modelled on a computer using the results of a comprehensive set of soil resistivity tests. Sections E8 & E9 provide guidance and specifications for design purposes.

However, this is not cost effective for distribution substations and pole transformers so we need to have some simple rules to determine ‘Hot’ or ‘Cold’.

These rules are:

‘Cold’ – if the installation is connected to a Primary or Grid Substation via an underground cable without any overhead line in the route. In this case the earth fault current will return to source via the cable sheath and not through the ground – little or no EPR will occur. HV & LV Earths can be combined.

‘Hot’ – if there is not a continuous underground cable back to the Primary or Grid Substation. Earth fault current will return to source through the ground and cause an Equipment

Potential Rise. You will assume that this EPR is above 430 volts and segregate the HV & LV Earths.

This approach errs on the side of safety.

We accept that sometimes earths will be unnecessarily segregated. This is particularly true in large villages or small towns which have a reasonably large earth system which is 'islanded' because the incoming circuits are overhead. If the cost of segregation is prohibitively high or impractical then the cost of a full earthing study may be justified.

If in doubt, treat it as 'Hot'.

3. Standard Distribution Earthing Methodology

To ensure that the numerous distribution installations we build are earthed both safely and cost effectively we have provided a standard earthing methodology contained in sections:

E3 Soil Resistivity Measurements

E4 Earth Electrode Resistance Tests

E5 Distribution Standard Earthing Layouts

By using these three documents you can predict the type and size of the earth system for the most common values of soil resistivity.

This will help you to advise landowners of the extent of proposed earthing excavation before work starts and to order sufficient earthing materials to complete the job in one stop.

4. Difficult or non-standard situations

The Distribution Standard Earthing Layouts are designed to cover the majority of situations and a standard solution should be your first approach. Sometimes this may mean placing a transformer some distance from a sensitive installation (such as a cellular phone mast or petrol station) in order to maintain proper HV/LV segregation.

However, there will be occasions where the standard job is not practical or the soil resistivity is so high that the standard solution advises you to seek specialist advice.

Practical solutions can be obtained but will normally involve a special soil resistivity survey and a computer modelling exercise by an earthing specialist. The cost of this has to be born by the project.

For advice please contact the East Midland Electricity Equipment Specialist responsible for earthing.

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Section E2

Earthing Guidance Notes

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1. INTRODUCTION

This series of guidance notes are intended to give the reader an understanding of the basic theory of distribution earthing, and to provide background information to the earthing specifications and standard earthing layouts.

Section **E8 - 132/33/11kV Earth Grid Design Guidance Notes** provides an in-depth guide to the design of bulk supply and primary substation earth design that complies with the requirements of the associated specifications.

2. EXPLANATIONS AND DEFINITIONS.

When a fault occurs on an electricity transmission or distribution network, it is possible for very large currents to flow in the general mass of earth. This current can cause a considerable rise in potential on earthed metalwork which may be accessible both to the public and to members of staff, particularly those who are carrying out fault switching. In addition, without adequate safeguards, it is possible for this excessive rise in potential to be transferred onto adjacent communication cables, and other power cables etc., creating potential danger to anyone who might be in contact. This may be some distance from the actual fault. It is thus essential that the earthing and bonding arrangements for equipment associated with public electricity supply be properly designed, correctly installed, and regularly tested and maintained.

Function of Earthing and Bonding. This is to :

- (a) Provide a low impedance path to enable fault current at any point on the electrical network to be returned to the transformer or generator neutral(s), without thermal or mechanical damage to connected apparatus, and to enable protective equipment to operate correctly.
- (b) Limit voltage rises, on all metalwork and the surface of the ground to which persons have normal access, to a safe value under all reasonably anticipated conditions. The earthing system should be so constructed as to prevent the establishment of dangerous potential differences between different parts of the substation which a person may be touching simultaneously.

The above are the functions of the earthing system, but when designing earthing systems it is important to recognise that they perform differently at high frequency (lightning) compared to power frequency (50Hz). This manual is primarily concerned with power frequency performance. Where appropriate, the standard earthing layouts have been developed to include high frequency aspects..

To help understand the definitions, a simple example is used:

Assume an earth rod of 2.4m length driven into the ground in an open field and a current is passed through it back to the source transformer earth.

Figure 1 shows the potentials that are established on the surface of the soil above the rod. The highest potential is directly above the earth rod (at A) and it falls off towards true earth potential as one moves away from it. The current flows through the ground to the source transformer taking a multitude of paths, but the current density is greatest nearest the rod.

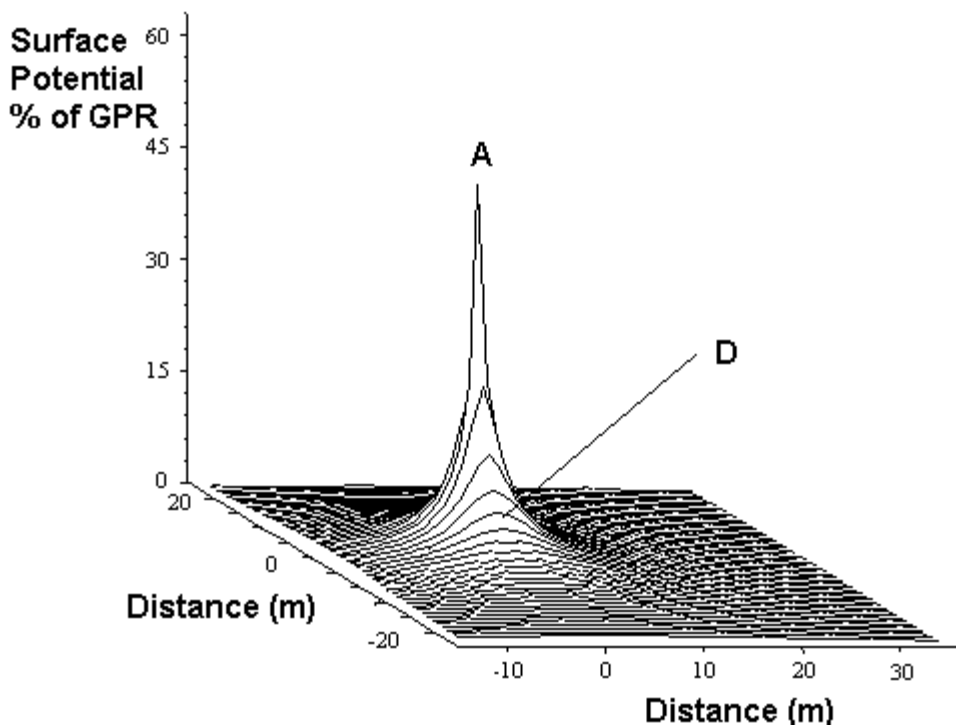


FIG.1. POTENTIAL ON SOIL AROUND EARTH ROD IN 3D.

3. DEFINITIONS OF GENERAL EARTHING TERMS.

Chain Impedance.

The steel foundation of a tower forms an earth electrode. When several towers are connected together via the earthwire, a ladder network is formed. The overall earth impedance of the circuit from a specified point is called the chain impedance. A Counterpoise Earth also exhibits chain impedance.

‘Cold’.

A “cold” substation is defined as a substation where the earth potential rise, under maximum earth fault current conditions, **does not exceed** the value specified in EATS 41-24. The values given are:

Circuits with standard protection	430 volts.
High reliability circuits with high speed protection. i.e. can clear an earth fault within 200 milliseconds	650 volts.

Earth Electrode.

These are conductors which are in direct contact with the soil and provide the conductive part in electrical contact with earth. They can include rods, tape, steel reinforcing bars and the sheaths of some types of cable.

Earth Electrode Current.

This is the maximum value of current which the earth electrode may be expected to pass during the lifetime of the installation.

Earth Electrode Impedance.

This is the impedance to the general mass of earth of an electrode at a given frequency. It may include contributions from other electrodes connected to it such as buried conductors, specific electrodes, cable sheaths, earthing of adjacent installations and all connected fortuitous electrodes.

Earth Electrode Resistance.

This is the DC resistance of the Earth Electrode and the general mass of earth.

Earth Grid.

For large area substations the earth electrode is normally run as a ring surrounding all the plant and equipment within the substation. The outer ring is then supplemented with cross-members run at 90° to each other, all connected together at crossing points and at the outer ring. This is known as the earth grid.

Earth Nests.

This is a collection of separate earth electrodes made up of rods and/or conductors specifically installed to make contact with the general mass of earth and connected together by a common metallic connection. The earth nest is to be kept free of any plant earthing connections and may be provided with facilities for isolation for testing purposes.

Earth Potential Rise (EPR.), Rise of Earth Potential (ROEP.) or Ground Potential Rise (GPR).

These are terms in common use meaning the same as the Earthing Conductor Voltage. This is the potential on exposed metalwork and the earth electrode during fault conditions, relative to remote earth. Note that its value will differ at points on a large earthing system.

Earth return path

The electrically conductive path provided by the Earth between earthing arrangements, for example between the two rods at A and B.

Earth surface voltage

The voltage between a specified point on the surface of the ground around the rod and reference (true) earth.

Earthing Conductor.

This is a conductor which connects plant and equipment to the earth electrode system. Examples include the above ground connections between substation equipment and the earth grid, together with the metallic sheath of an underground cable which has an insulated serving.

Earthing Conductor Voltage.

This is the voltage between the earthing conductor and reference (true) earth.

Equipotential Bonding.

This is the provision of electrical connections between conductive parts intended to achieve equipotentiality.

Functional Equipotential Bonding.

Equipotential bonding for purposes other than safety. e.g. additional bonding in computer installations to prevent equipment malfunctions.

“Hot” Substation

A “hot” substation is defined as a substation where the rise of earth potential, under maximum earth fault current conditions, can exceed the value specified in E.A.T.S 41-24. The values given are:-

Circuits with standard protection	430 volts.
High reliability circuits with high speed protection. i.e. can clear an earth fault within 200 milliseconds	650 volts.

As a general rule, the 650V value would only normally apply to 132kV and higher voltage equipment and to some 33kV equipment.

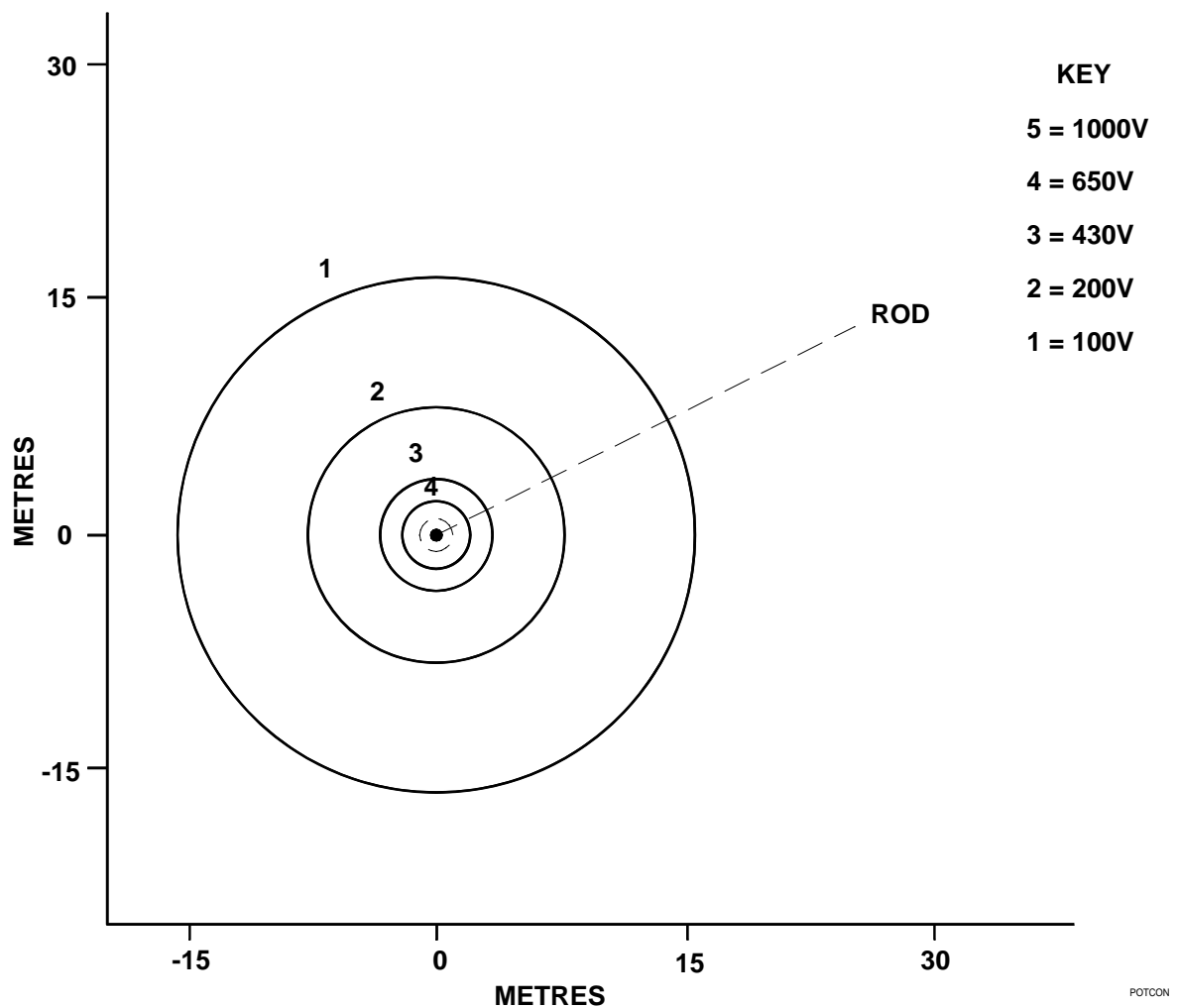
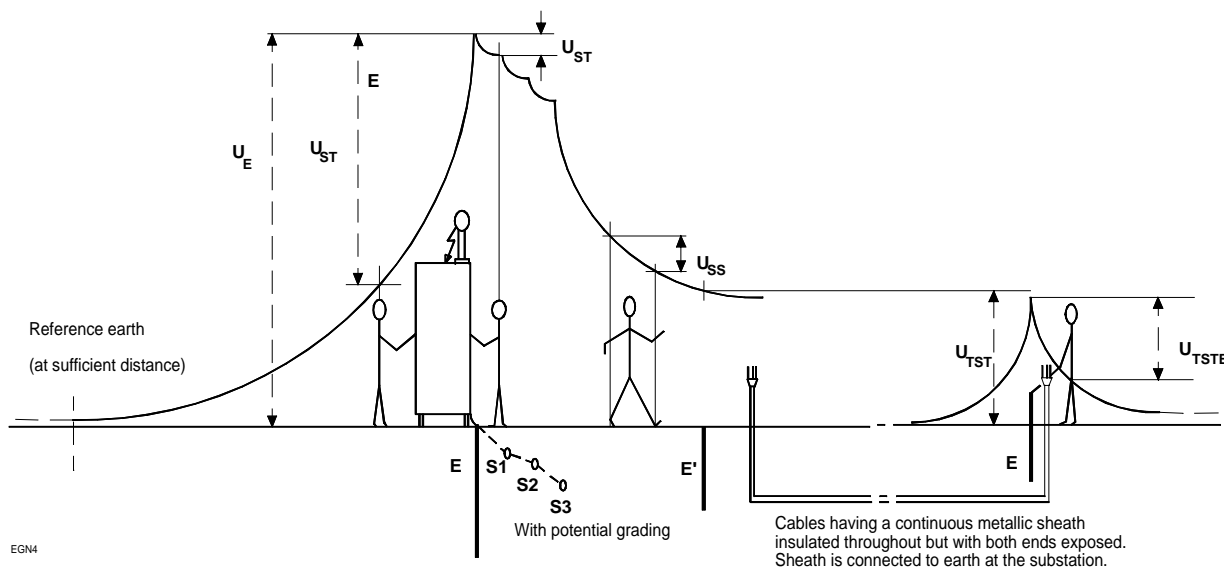


FIG.2. POTENTIAL CONTOURS ON SOIL SURFACE AROUND EARTH ROD.

“Hot” Zone.

In figure 2, the potentials on the surface of the soil around the earth rod have been represented as equipotential lines. This is the same effect as would occur for a substation, except that the lines would follow the shape of the electrodes installed, so would not normally be circular. If the rise of earth potential at the substation exceeds the 430/650V limit, then the equipotential line coinciding with the 430 or 650V contour would need to be identified. The area within the substation and up to the appropriate contour line is known as the “hot zone”. Special precautions are necessary where there are any buried metallic services situated within this “hot-zone” area.



E	Earth electrode.
U_E	Earth Potential Rise - EPR (Ground Potential Rise GPR)
$S1, S2, S3$	Potential grading earth electrodes (e.g. ring earth electrodes or perimeter earth conductor), connected to the earth electrode (rod) E .
U_{ST}	Source voltage for touching. (touch voltage)
U_{SS}	Source voltage for stepping. (step voltage)
U_{TST}	Transferred source voltage for touching if the sheath is not earthed at the remote end. (transfer potential)
U_{TSTE}	Transferred source voltage for touching if the sheath is earthed at the remote end as well. (remote touch voltage)

FIG.3. TOUCH, STEP AND TRANSFER POTENTIALS AT AN ELECTRICITY SUBSTATION.

Having described the standard terms and potentials for a simple example, Figure 3 (which is taken from the European Standard) illustrates the potentials for a typical substation situation. The European symbols and descriptions are included for reference and the generally accepted UK equivalent term is included in brackets. As can be seen from the U_{TSTE} symbol, it is necessary to consider connected earth electrodes at a remote point and this is precisely the arrangement where a remote distribution substation is connected to a primary substation via a plastic sheathed 11kV cable.

Main Switchgear Earth Bar.

The earth bar to which all indoor equipment is connected. In substations with frame leakage protection fitted, the bar will be split. Exposed switchgear metalwork will be connected to one section and the earth grid and incoming cable sheaths to the other.

Protective Equipotential Bonding.

This is equipotential bonding for the purpose of safety.

Resistance Area

The resistance area of a rod is that area around it where most of the voltage drop occurs. For a 2.4m rod in soil of uniform resistivity, this would be the area within 4 to 6 metres radius of the rod, for a moderate current flow. The radius would increase if the magnitude of the current increased or in non-uniform soils which have high resistivity lower layers.

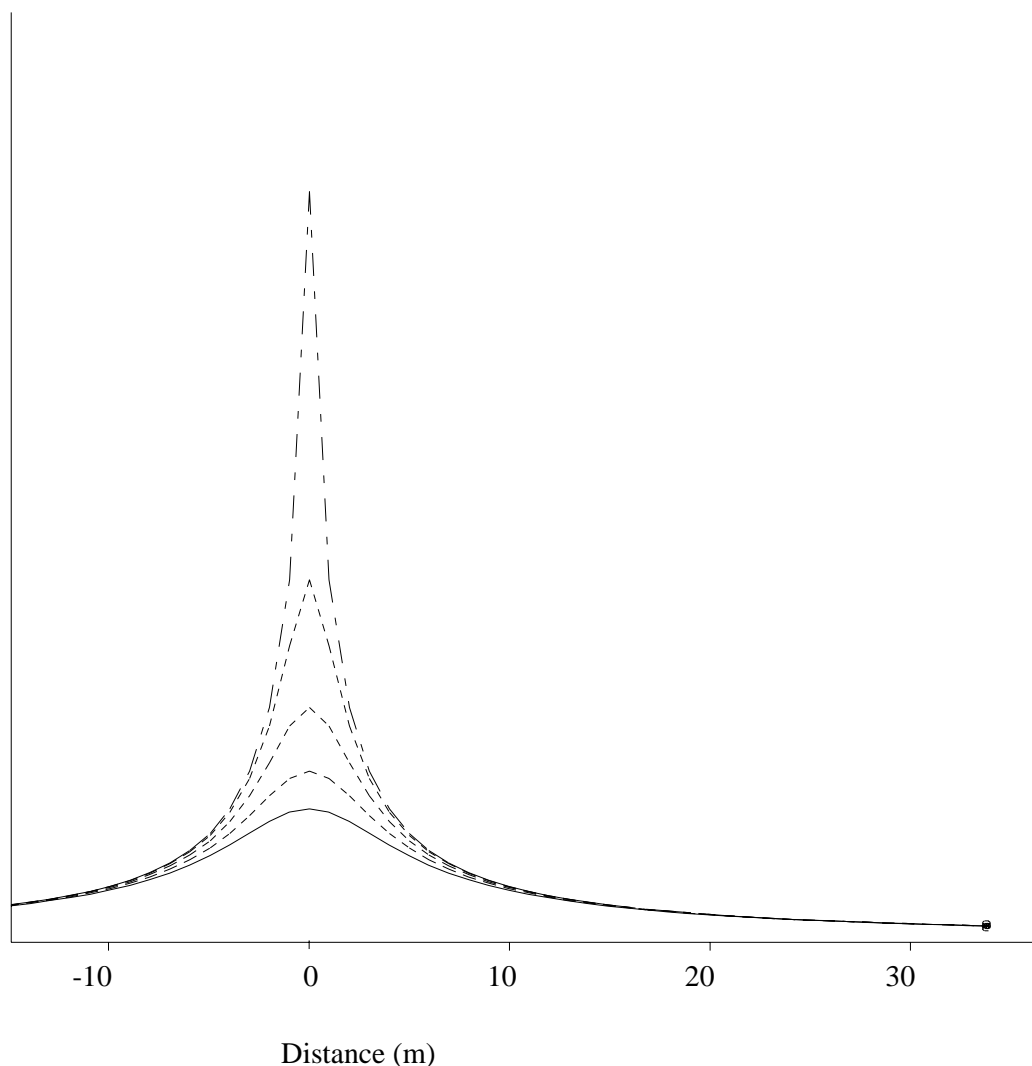


FIG.4. POTENTIAL ON SOIL SURFACE NEAR EARTH ROD, 2D VIEW.

Soil Resistivity

This is the resistivity of a typical sample of soil.

Step Potential.

As demonstrated in Figures 1, 2 and illustrated in figure 3, there will be potential differences established on the surface of the soil whilst fault current is flowing. The magnitude of the potential difference a person walking in the area would experience depends on the orientation of the feet with respect to the voltage contours and the distance between feet. Step voltage in a particular direction is defined as the potential difference between two points one metre apart. It is greatest adjacent to the electrode. Step potentials are those normally responsible for the death of animals, such as cattle and horses, during fault conditions.

Substation Main Earth Bar.

This is a central conductor to which all earthing and bonding conductors are connected. It is normally situated above ground but may be buried.

Touch Potential

Figure 2 shows the potential on the surface of the soil surrounding rod A as a plan view in two dimensions. If, during the time that fault current flows, a person were to touch the rod (or any exposed metalwork connected to it), then the potential difference experienced between hands and feet is termed the touch voltage. This is illustrated in Figure 2 and it is clear that it increases with distance of the person's feet from the rod.

Transfer Potential

At position D in figure 1, the potential on the soil surface is higher than true earth, but significantly lower than that at rod A. If the wire of an insulated conductor was connected to rod A and extended to position D, then there would be a potential difference between the end of the wire and the surface of the soil at D. If a person was able to touch the wire, whilst standing at D, an electric shock may be experienced. This potential difference is termed the "transfer potential". The transfer potential in AC systems has a maximum value equal to that of the rise of earth potential, such as at rod A. Special precautions are necessary to guard against excessive transfer potentials.

True or Reference Earth

With respect to each rod is the potential on the surface of the soil a significant distance away, i.e., outside the resistance area, such as point E in Figure 1. Because it is outside the influence area of the rods, the electrical potential there is conventionally taken as zero.

4. DEFINITIONS OF TERMS ASSOCIATED WITH POWER SYSTEMS.

Counterpoise Earth.

An earth electrode system consisting of a single horizontal conductor and a number of vertical rods buried in the ground.

A Counterpoise Earth is used in high soil resistivity areas in addition to a main earth electrode. A Counterpoise Earth may consist only of horizontal conductor in rocky areas where the topsoil lies on rock. Very long Counterpoise Earths have the disadvantage of exhibiting high impedance to lightning surges.

Crowsfoot Earth.

An earth electrode system consisting of a number of Counterpoise Earths radiating from the main earth electrode at 45° or 90° angles. A Crowsfoot Earth is used in high soil resistivity areas to limit the impedance of an earthing system which has lightning protection duties e.g. a pole transformer earth.

Deep Earth.

A earth electrode system consisting of a single vertical conductor driven deep into the ground to give a direct path to earth for lightning protection. Often difficult to install in areas of high soil resistivity or rocky ground where it must be augmented by either a Counterpoise or a Crowsfoot earth.

Exposed Conductive Part.

Conductive part of equipment and which is not normally live, but which can become live when basic insulation fails.

Independent Earth Electrode.

An earth electrode located at such a distance from other electrodes that its electrical potential is not significantly affected by electric currents between Earth and other electrodes.

Lightning Conductor.

A conductor appropriately placed on a structure to conduct lightning current to an earthing arrangement.

Mid-Point Conductor.

The conductor electrically connected to the mid-point and capable of contributing to the distribution of electrical energy.

Neutral Point.

The common point of a star connected polyphase system or the earthed mid- point of a single phase system.

Neutral Conductor.

The conductor electrically connected to the neutral point and capable of contributing to the distribution of electrical energy.

Parallel grounding conductor.

A conductor laid along the cable route to provide a low impedance connection between the earthing arrangements at the ends of the cable route.

Power System Earthing.

Functional earthing and protective earthing of a point or points in an electric power system.

Protective Conductor.

A conductor provided for the purposes of safety (protection against electric shock).

Perimeter Earth Conductor

This is a conductor laid around the outside of a piece of plant to provide an equipotential zone around equipment which has exposed metalwork connected to the HV earthing electrode. Examples may include: Padmount Transformer, metal clad Compact Unit Substation, palisade substation fence.

Underground cable route earth electrode.

Earth electrode usually laid along the cable route, protected if required against corrosion, to provide earthing along its route.

5. DEFINITIONS OF TERMS ASSOCIATED WITH OPERATIONAL WORK.**(to) Earth (verb).**

To make an electrical connection between a given point (in a system or in an installation or in equipment) and a local earth.

Note :- The connection to the local earth may either be intentional or unintentional (accidental) and may be either temporary or permanent.

Earthing for Work.

Earthing normally live parts so that work may be performed without danger of electric shock.

Note :- For other earthing terms associated with operational work e.g. circuit main earth, local earth, portable earth etc. reference should be made to the relevant operational safety manual.

Section E3

Soil Resistivity Measurements

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Revision Log For Section E3 Soil Resistivity Measurements

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Section	Notes about the change
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Section	Notes about the change
2	One rod method – table for 1.2m rod included
5	Urban networks – ‘Global Earthing System’ section added

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1. Introduction

The measured resistance of an electrode is dependent upon the resistivity of the ground surrounding it. The resistivity of the ground varies considerably from a few ohm.metres (Ωm) to thousands of Ωm . As the resistivity increases so does the amount of electrode you need to install to achieve your required electrode resistance. Installing more electrode will also increase the cost and time of installation which could be considerable in difficult ground conditions. The resistivity of the ground varies seasonally and annually depending on the weather conditions. This factor has been taken into account in the electrode systems described in **Section E5 - Distribution Standard Earthing Systems**.

It will be advantageous to know approximately how much earth electrode you will need to install prior to the actual installation. This will allow you to cost the work correctly and minimise the disruption to job scheduling.

You should always:

- **Determine the soil resistivity using one of the methods outlined in this document**
- **Use the results to predict the earthing system required**

at the planning stage of each project.

This document provides three different ways to obtain a soil resistivity value that you can use to determine the approximate amount of electrode to install to achieve your required electrode resistance value.

Note: Once the electrode has been installed you must measure and record the actual resistance of the electrode. Sometimes you may need to install more earth rods to lower the resistance that stated in the relevant earthing specifications. This may happen where the soil does not have a uniform resistivity.

Once a resistivity value has been arrived at using one of the methods below this can be used to select an earth electrode design. See **Section E5 - 11kV Distribution Standard Earthing Layouts** to choose a design that will comply with the required specification.

2. Method A - One Rod Method

This method is very quick, simple and gives very practical results.

It requires a 5/8" earth rod to be installed. When this method is used at the planning stage the rod may be installed in a position where it can be included in the final electrode installation. If the approximate soil resistivity has been predicted from local knowledge or geographical data you should use this procedure as soon as you start work at the site. This will then give you the maximum amount of time to organise extra materials if your prediction is wrong.

If you cannot drive a 2.4 or 1.2 metre rod in to it's full depth it is an indication that you may have a layer of high resistivity ground below the immediate surface. In this case Method B will provide you with more meaningful information.

1	Install a 5/8" copper bonded rod with the top of the rod exposed 0.5m below ground level.
2	Measure the rod's resistance using the three terminal resistance meter (or 4 terminal with C1 and P1 shorted) See Section E4 - Earth Electrode Resistance Test
3	Lookup TABLE 1 and read off the soil resistivity from the resistance you measured on the rod. Alternatively multiply the resistance by 2.45 for a 2.4m rod or 1.39 for a 1.2m rod
4	Use Section E5 - 11kV Distribution Standard Earthing Layouts to find type of earth you need to install.

TABLE 1. ROD RESISTANCE CONVERSION TO EQUIVALENT SOIL RESISTIVITY

Resistance of 1 x 2.4m Rod (ohm)	Resistance of 1 x 1.2m Rod (ohm)	Equivalent Soil Resistivity (ohm.m)
0 - 10	0 - 17	1-24
11 - 24	19 - 42	26 - 58
25 - 36	44 - 64	61 - 89
37 - 46	65 - 82	90 - 114
47 - 56	83 - 100	115 - 139
57 - 66	101 - 118	140 - 164
67 - 74	119 - 133	165 - 184
75 - 82	134 - 147	185 - 204
83 - 91	148 - 162	205 - 225
92 - 100	163 - 180	226 - 249
101 - 108	180 - 190	250 - 264

If the resistance of the rod is higher than the values shown in the table, you should use Method B “Four Terminal Soil Resistivity Measurement”. This will help you to determine if there are lower resistivity soil layers that can be made use of by installing deeper electrodes, or whether a specialist design is required.

3. Method B – Four Terminal Measurement

This method requires a soil resistivity test needs to be carried out using a four terminal earth testing instrument. It is more time consuming than the “One Rod Method” but it does help you to decide on deep or shallow earths when conditions are difficult.

The route chosen for the tests should preferably be in undisturbed soil, away from any known cable/pipework routes, and at least 10m away from the boundary of an EHV substation. Readings are to be taken at the different values of ‘a’ shown in Table 2. Note that it is important to ensure that measurements are symmetrical about point X, midway between the voltage rods. The test should be repeated at approximately right angles to the first.

If there are large fluctuations in the measured values between the two sets of readings at the same spacing, then it is likely that interference from buried cables/pipes or stray ground currents are present. Additional sets of readings must be taken at locations a few metres away. If the problem persists, then measurements at a more distant, representative site are required.

Fig.1. shows the general measurement arrangement. The four earth rods should be driven into the ground in a straight line, at a distance ‘a’ metres apart and driven to a depth of ‘d’ metres where ‘d’ = ‘a’/20 . The actual dimensions are given in Table 2.

FIG.1. SOIL RESISTIVITY TEST

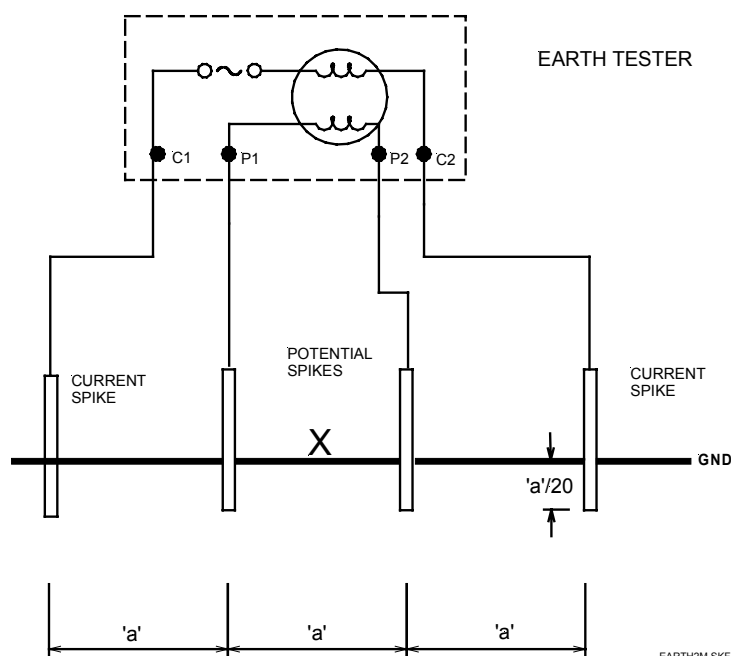


TABLE 2. PROBE SPACING AND PROBE DEPTHS

Applicable to Installations up to	Probe Spacing 'a' Metres	Probe Depth 'd' Metres
11/0.415kV	0.5	0.02
	1.0	0.05
	2.0	0.05
	3.0	0.10
	6.0	0.10
	9.0	0.10
	14.0	0.10
33kV	18.0	0.15
	22.0	0.15
	25.0	0.15
132kV	50.0	0.20

The four rods are connected to the tester, as shown in Fig.1., with the outer rods connected to the C-1 and C-2 terminals, and the inner rods to the P-1 and P-2 terminals. At each spacing measure and record the instrument reading.

Note: On most earth resistivity tester terminals C1 and P1 can be shorted to enable the instrument to measure electrode resistance. Ensure that these two terminals are not shorted out whilst carrying out a resistivity test as you will get a false reading.

1.1 Interpreting the Measurement Data

Having obtained the test results the following formula has to be applied to the results:

$$\text{Soil Resistivity } (\Omega \text{ m}) = 2\pi aR$$

Where: 'a' is the distance between the test rods

R is the average reading (since a minimum of two sets of readings should be taken) from the instrument at the distance 'a'

Example 1

Distance 'a' (m)	Instrument Reading 'R'	Calculation	Soil Resistivity (Ω m)
0.5	4	$2 \times \pi \times 0.5 \times 4$	13
1	5	$2 \times \pi \times 1 \times 5$	31
2	2.5	$2 \times \pi \times 2 \times 2.5$	31
3	1.7	$2 \times \pi \times 3 \times 1.7$	32
6	4	$2 \times \pi \times 6 \times 4$	150
9	3	$2 \times \pi \times 9 \times 3$	170
14	2.3	$2 \times \pi \times 14 \times 2.3$	202
Average			90

Note that the resistivity in this example is lowest where 'a' is less than 3 metres. This means that "shallow earthing" may be more successful than "deep earthing".

Example 2

Distance 'a' (m)	Instrument Reading 'R'	Calculation	Soil Resistivity (Ω m)
0.5	50	$2 \times \pi \times 0.5 \times 4$	157
1	30	$2 \times \pi \times 1 \times 5$	189
2	14	$2 \times \pi \times 2 \times 2.5$	176
3	6	$2 \times \pi \times 3 \times 1.7$	113
6	2	$2 \times \pi \times 6 \times 4$	75
9	1.3	$2 \times \pi \times 9 \times 3$	74
14	0.8	$2 \times \pi \times 14 \times 2.3$	70
Average			122

Note that the resistivity in this example is lowest where 'a' is greater than 6 metres. This means that a small number of long earth rods ("deep earthing") will be more successful than a lot of short rods ("shallow earthing").

In most cases taking the average of the soil resistivity values will give a conservative value that can be used to select a design.

For large earth electrode installations, such as at 132/33kV and 33/11kV substations, the soil resistivity data will be used to create a soil model, using specialist software, to enable the electrode installation to be designed in detail.

4. Method C - Geological Survey Data

Whilst less accurate than direct measurement, geological data can give a reasonable indication as to the resistivity of the ground in a particular area.

You may also find it useful to build up a data base of resistivity measurements from actual jobs.

By using these two sources of information you can determine how much electrode to install at most job locations without the need for a preliminary survey. This will save time and cost.

Of course – you MUST MEASURE the actual resistances of your earth system after installation to confirm your predictions.

In the short term the geological data can be obtained from the one inch series ‘Solid and Drift’ edition geological survey maps published by:

British Geological Survey, Keyworth, Nottingham, NG12 5GG
Tel. 0115 9363100

These maps are colour coded to show different underlying geological types and surface deposits such as clay and head. The following table gives typical resistivity ranges for a number of different ground types.

This method shall not be used in isolation where extensive earth installations are going to be installed such as at primary and bulk supply point substations. Accurate soil resistivity measurements and soil modelling techniques are essential to the proper design process.

However, geological information can be useful when short-listing possible sites. It may help you to choose a site with low earth resistivity instead of a site with high resistivity. Intelligent site selection can considerably reduce the cost of earthing and also remove/reduce the implications of creating a “Hot Zone”.

TABLE 3. GEOLOGICAL RESISTIVITY

Ground Type	Indicative Resistivity ohm.m
Mercia Mudstone	20
Coal Measures	20
Loam	25
Alluvium	35
Boulder Clay	50
Keuper Marl & Waterstones	50
Head	70
Sand/Gravel	300
Limestone	300
Pebble Beds	300
Permian Limestone & Marl	400
Gritstone	1000

Where the maps indicate very high soil resistivities such as limestone, granite, gritstone etc. it is recommended that a soil resistivity test is carried out as the cost to install the earth electrode could be a significant proportion of the cost of the overall job.

5. Urban Networks –‘Global Earthing System’

Urban networks generally comprise of an extensive network of earth electrodes and metallic sheathed cables. Together these form a large area earth electrode in their own right which provides a low resistance to earth even in high resistivity soils. This type of system is referred to as a ‘Global Earthing System’

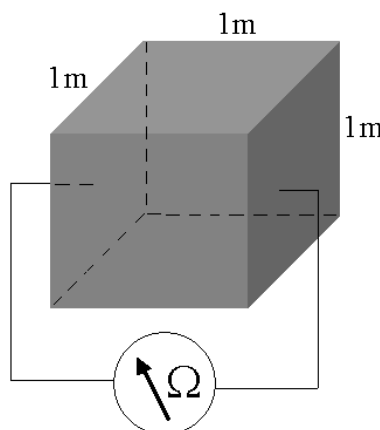
It is often difficult or impossible to make meaningful soil resistivity measurements in urban areas due to the existence of paved surfaces and numerous underground metallic objects.

For the purposes of this manual East Midlands Electricity defines a **Global Earthing System** as any urban or suburban network comprising of mainly metallic sheathed cables which has an area **greater than 10km²** . You may assume that a Global Earthing System has a **nominal soil resistivity of 150 Ω m** .

6. What is an ohm.metre? Explanatory Note

Resistivity is expressed in ohm.metres. An ohm.metre is defined as the resistance of a cube of material measuring 1m x 1m x 1m

If you can imagine two metal plates fixed either side of the cube then the resistivity is the resistance measured between these two plates



Section E4

Earth Electrode Resistance Test

132kV, 33kV, 11kV & 0.4 kV

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Section	Notes about the change
2.1.2	Explanatory note on fall of potential method added
3	Hot zone 430 volt contour – measurement on site – new section added

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1. INTRODUCTION

This document describes the different methods of measuring the earth electrode resistance. The main reason for measuring the electrode resistance is:

1. New installations - to ensure that it is equal to or less than the design value.
2. Existing installations - to ensure that it is equal to or less than the required value, but mainly to ensure that it has not substantially changed from its original value unless by design.

The correct resistance value is required to:

1. Ensure that protection is operated to disconnect the power source under earth fault conditions.
2. Ensure that the Earth Potential Rise under earth fault conditions does not present a danger to staff or public.

There are situations, typically at existing 132/33kV or 33/11kV substations, where it is not practicable to directly measure the earth electrode resistance. Alternative methods of proving the integrity of the earth are described in **Section E12 - Earthing Maintenance 132/33/11kV Substations**.

Section 3 describes a method of measuring the actual hot zone 430 volt contour where the standard HV/LV electrode separation distances described in E5 'Distribution Standard Earthing Layouts'

2. Earth Electrode Resistance Measurements

Three measurement methods are described in this specification. Each is appropriate for particular types of plant:

Test	Type of Plant
Method 'A' - Three Terminal Fall of Potential (Dead)	New electrodes disconnected from plant.
Method 'B' - Three Terminal Fall of Potential (Live)	Pole transformers, reclosers, ABSDs without HV cables on the same pole.
Method 'C' - Clamp Meter Test (Live)	Substations, Padmounts, Cable Pole Terminations, Pole Transformers with HV cables on the same pole.

2.1 Method 'A' - Three Terminal Fall of Potential (Dead)

Warning.

This test is only to be used on installations that are NOT connected to the distribution system.

This method is suitable for the following situations:

1. All earth electrode installations prior to their connection to the distribution network.
2. Earth electrode installations that can be safely disconnected from the distribution network.

A version of this test is suitable for isolated earth installations that remain connected to the distribution network; see section 2.2

2.1.1 Procedure

The following procedure describes the electrode resistance measurement for a small area electrode installation. For example an installation consisting four sets of 2.4m rods arranged in a 3.5m x 3.5m square formation as may be installed at a ground mounted distribution substation.

The distances used should be increased in proportion to the size of electrode under test. For example the distance of the current electrode should be approximately 6-10 times the diagonal distance of a rectangular electrode installation, or 6-10 times the length of a counterpoise electrode system. For a Grid/Primary substation this will mean the current probe will be several hundred metres away which will require test leads to be made up to suit. The standard lead kit provided with the measurement instruments typically only comes with 50m leads.

A 3 or 4 terminal earth tester will be used for measuring the electrode resistance. On a 4 terminal tester, terminals P1 and C1 are to be shorted together. The equipment should be connected as in Fig.1.

The current spike is to be placed approximately 50m away from the electrode under test, preferably at right angles to any buried cables or pipes, and connected to terminal C2 of the test instrument. The voltage rod is to be placed at approximately 30m from the electrode under test, and connected to terminal P2. Terminal P1-C1 is then to be connected to the electrode under test.

Three readings are to be taken at 50%, 60% and 70%, one with the voltage rod at 30m (60%) then with the voltage rod at 25m (50%), and finally with the rod at 35m (70%). If the second two readings are within 5% of the first reading, the first reading is to be taken as the correct resistance value for the electrode.

If the two readings vary by more than 5% of the first reading, the current rod needs to be moved 20m further out and another set of three readings taken until the readings fall below the 5% requirement. Remember that the voltage probe should be placed at 50%, 60% and 70% of the distance between the electrode and the current probe.

These measurements are to be taken before the electrodes are connected to the steelwork or plant items.

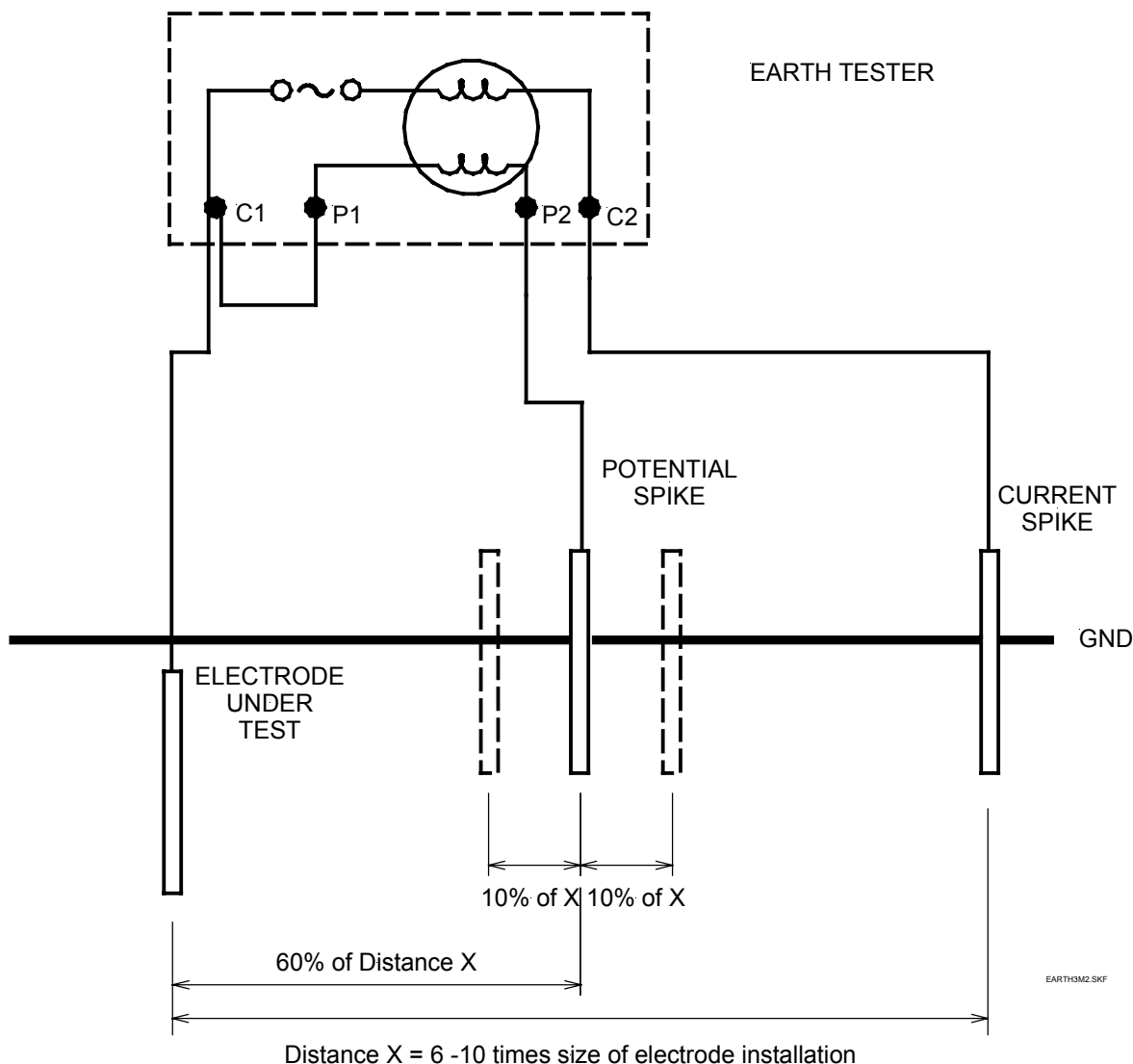
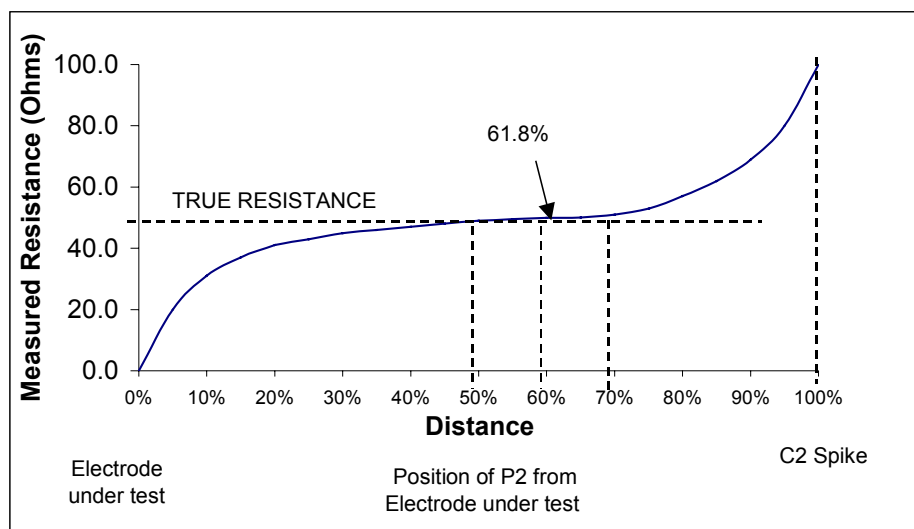


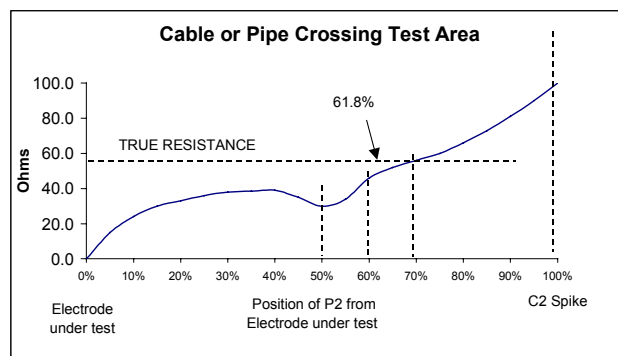
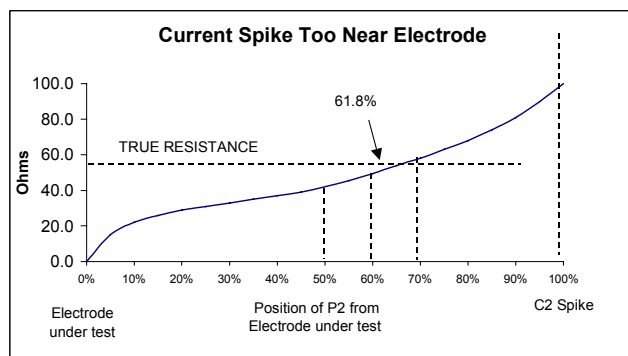
FIG.1. EARTH ELECTRODE RESISTANCE MEASUREMENT

2.1.2 Explanatory Note – why check the readings at 50%, 60%, & 70% ?

The reading on the earth tester will vary according to the distance of P2 from the electrode under test. If you plot a graph of P2 readings against distance you should get a curve as shown below. As you can see, the curve flattens out at around 50% to 70% and according to Dr G.F. Tagg the theoretically correct resistance is measured at a point 61.8% of the distance between the test electrode and the C2 spike.



Therefore you could take only one reading at 61.8% and use that as the electrode resistance. However, if the C2 probe is not far enough away from the electrode under test (remember it should be 6 to 10 the size of the electrode under test) then the curve will not flatten out properly. Further more if there is a metal object in the ground on the route then the curve will be distorted. Either way the readings will not be within 5% of each other and the resistance reading will not indicate the true resistance of the electrode under test. Therefore 5% check on the three readings helps to confirm that you have made a valid test.



2.2 Method 'B' - Three Terminal Fall of Potential (Live)

Method 'B' is used for HV earth electrode measurements without making the system dead or isolating the electrode on pole transformers and reclosers where they are not connected to any other remote earth systems.

Pole installations that include an HV cable termination cannot be tested live by Method 'B'.

The reason for this is that if the earth electrode is tested at the pole whilst the cable sheath is still connected, the measurement will give the value for all the other earth electrodes connected along the sheath of the cable. This will result in a much lower value than the actual value. It would even give you a value if the electrode at the pole position had been removed.

If you need to test the earth electrode then either :

The plant must be made dead and the electrode under test must be disconnected from the cable sheath and tested by Method 'A'

or

Use Method 'C'

2.2.1 Procedure

To carry out electrode measurements on live pole installations the following procedure must be complied with.

1. Set up the test equipment as in section 2.1.1 but do not connect the test lead to the electrode under test.
2. The test lead that is to be connected to the electrode under test is be fitted with a live line tap.
3. Apply the live line tap to the main earth conductor or, if it is insulated, the earthed steelwork at a height of 3m above ground level using a live line tapping stick.
4. The operator carrying out the testing must wear rubber gloves.
5. The test is then to be carried out in the same manner as in section 2.1.1 making sure to disconnect the voltage test lead (P2) from the instrument prior to moving the test rod, reconnecting the test lead (P2) once the test rod has been moved.
6. On completion of the test remove the live line tap first using live line tapping stick.

Should the need arise to move the current test rod (C2), then the current lead (C2) should be disconnected from the instrument prior to moving the rod, reconnecting the lead once the rod has been moved.

2.3 Method 'C' - Clamp Meter Test (Live)

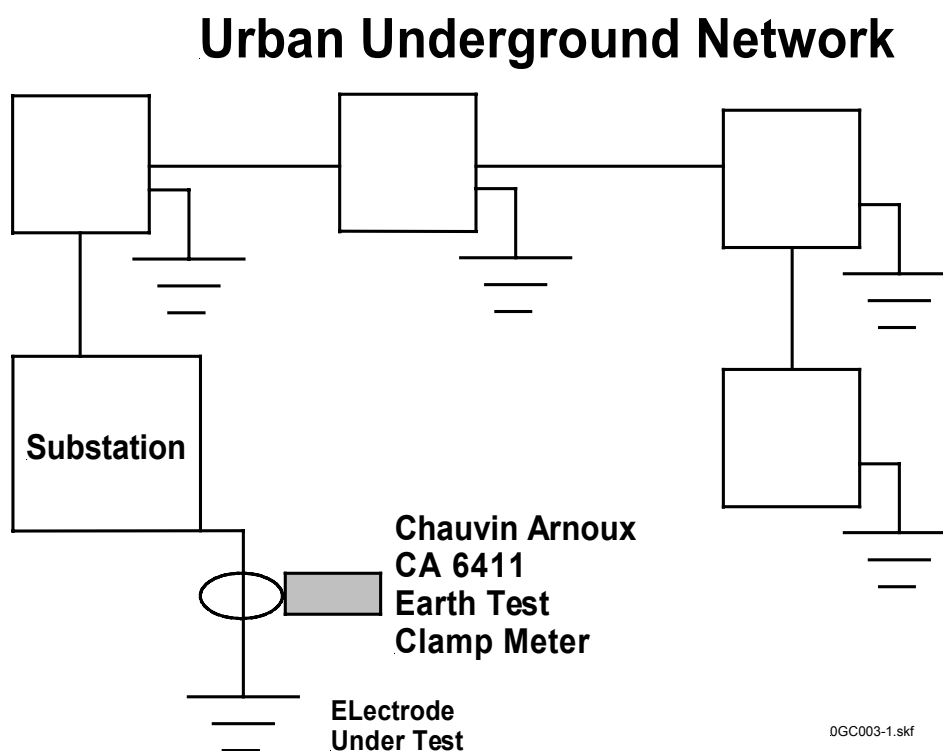
The Chauvin Arnoux C.A.6411 earth resistance clamp meter is recommended for this test. **Standard clip-on ammeters will not work.**

This method can be used to measure the resistance of earth electrodes attached to energised plant. It is non-intrusive and does not require the earth electrode to be disconnected from the plant. However, **it cannot be used on isolated earths.**

This test is suited to measuring small area electrodes that are interconnected to a low resistance earth system. A typical example would be an earth electrode at an 11/0.4kV ground mounted distribution substation embedded in an extensive underground network.

This method relies on the local electrode resistance being much higher than the earthing system it is connected to. It is, therefore, not suitable for measuring isolated earth electrodes such as those found at pole transformer locations unless there is a HV cable also on the pole.

FIG.2. CLAMP METER TEST



For a correct reading the clamp meter needs to be attached to the main earth lead attaching the item of plant with the local buried earth electrode. Consult the user manual of the measurement equipment for correct operation.

3. Hot zone 430 volt contour – measurement on site

The HV / LV earth electrode separation distances shown in E5 'Distribution Standard Earthing Layouts' have been calculated using general assumptions about the soil resistivity and structure. In order to 'fail safe' the distances have taken into account fairly poor conditions. These can result in distances that are greater than would result from the more favourable soil structure at an individual site.

On some jobs you may find that these separation distances are too big for the size of the site. In these cases it may be worth the effort of directly measuring the 430 volt hot zone contour of the HV earth electrode. The LV electrodes can then be placed just outside the actual 430v contour.

This test is a variation on the Three Terminal Fall of Potential Test and can be carried out when you test the HV electrode.

3.1 Procedure

1. First establish the Equipment Potential Rise (EPR)

To work out the EPR you need to know:

The value of the Neutral Earth Resistors at the Primary S/S Z_{NER}

The impedance of the 11kV circuit Z_{Line}

The resistance of the HV new earth electrode Z_{earth}

The earth fault current I_F will be: 6,300v divided by $(Z_{NER} + Z_{Line} + Z_{earth})$

The EPR is then calculated by simple Ohms Law $EPR = I_F \times Z_{earth}$

2. Then work out the resistance the P2 probe will read at the 430 volt contour position.

The resistance reading at the 430v contour will be:

$$R_{430v} = (EPR - 430) \text{ divided by } I_F$$

To find the 430v contour set up the Three Terminal Fall of Potential Test as in Method A and keep moving the P2 probe nearer to the electrode under test until the instrument reads the same value as R_{430v} ohms. This will be the edge of the 430 volt contour.

Example

Primary S/S has two NERs each 6.4 ohms in parallel	$= 3.2 + j0 \text{ ohms}$
10 km of 100 acsr O/H line $0.237 + j0.375 \text{ ohms / km}$	$= 2.37 + j3.75 \text{ ohms}$
New HV earth electrode measured at 20 ohms	$= 20 + j0 \text{ ohms}$
Total $= 25.57 + j3.75 \text{ ohms} = 25.84 \text{ ohms impedance}$	

Earth fault current $I_F = 6,300 / 25.84 = 243$ amps

$$\mathbf{EPR} = I_F \times Z_{\text{earth}} = 243 \times 20 = \mathbf{4,876 \text{ volts}}$$

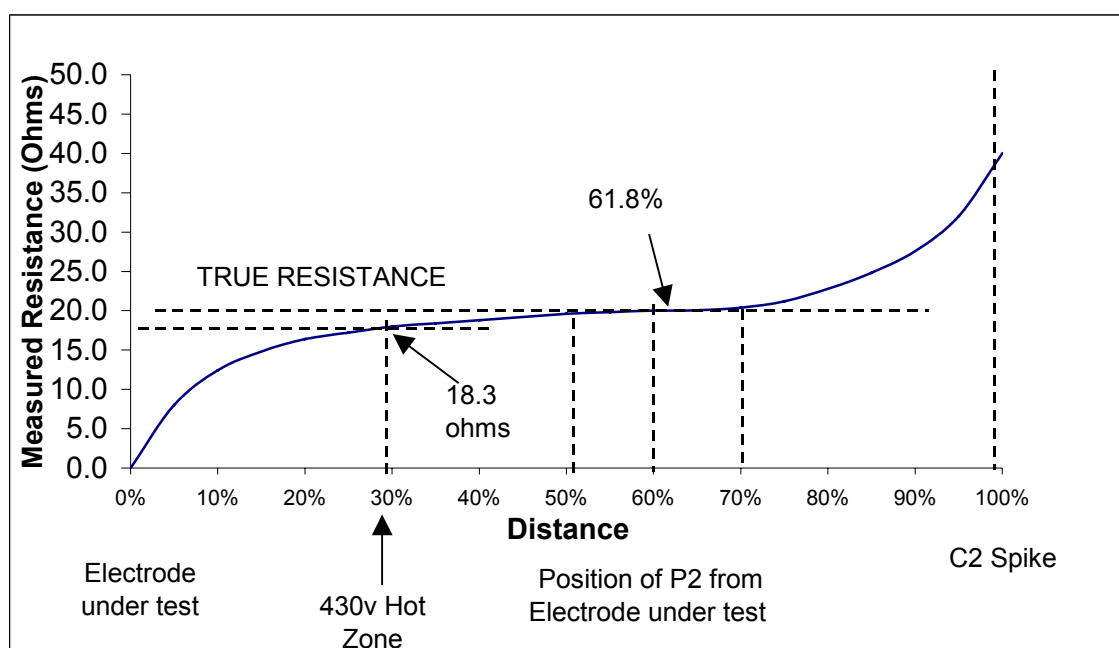
$$\mathbf{R_{430v}} = (EPR - 430) \text{ divided by } I_F$$

$$= (4876 - 430) / 243$$

$$= 4446 / 243$$

$$= 18.3 \text{ ohms}$$

Remembering the curve in the explanatory note about the Fall of Potential method the 430v contour should appear like this:



Section E5

Distribution

Standard Earthing Layouts

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Section	Notes about the change
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Changes made in version 2 Jan 2002

Section	Notes about the change
9.2	Assumptions explained: Urban networks – ‘Global Earthing System’ Number of rods Deep earths HV/LV separation distances
11	Requirement to bond the LV cable to the LV neutral earth electrode introduced Explanatory notes about assumptions added
12	Bottle ends and joints within the hot zone – warning against fitting the PME earth electrode

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1. INTRODUCTION

This document provides standard earthing layouts and methodologies to enable you to meet the earthing installation specifications required by East Midlands Electricity .

2. GENERAL

The earth grid design will provide for the following functions:

- (a) Provide a low impedance path to enable fault current at any point on the electrical network to be returned to the transformer or generator neutral(s), without thermal or mechanical damage to connected apparatus, and to enable protective equipment to operate correctly.
- (b) Limit voltage rises on all metalwork and the surface of the ground to which persons have normal access, to a safe value under all reasonably perceived conditions. The earthing system will be so constructed as to prevent the establishment of dangerous potential differences between parts of the substation, which a person may be contacting simultaneously.

Attention

Caution is required when siting open-to-touch equipment such as Automated Pole Mounted Reclosers, Padmounts, Metal Clad Compact Unit Substations and Metal Fenced Out-door Substations. There is a danger of significant transferred touch potentials arising between the equipment metalwork and adjacent remotely earthed metalwork such as street furniture or fencing. The equipment is to be sited such that a minimum separation of 3m is maintained between the equipment and remotely earthed structures. In high-risk areas such as near schools, playing fields, bus stops etc. an insulating barrier such as a fence, wall, or glass-reinforced plastic should be installed to minimise the risk. When in doubt, advice must be sought from Asset Development.

3. TECHNICAL SPECIFICATIONS

Your earth electrode design will comply with:

The Powergen Engineering Minimum Standard “The Design, Application, Testing and Maintenance of Earthing Systems”

and

East Midlands Electricity Local Management Instruction for Distribution System Earthing.

4. EARTH POTENTIAL RISE (EPR)

These standard designs make the following assumptions:

Cold Sites - Plant fed by an all underground cable system that has a continuous metallic sheath path back to the Primary / Grid Substation will assumed to have an EPR below 430v and the plant will be classified as 'cold'. *This requirement includes both the normal and alternative feed.*

Hot Sites – Plant fed by a system that has any Overhead Line in the circuit back to the Primary / Grid Substation will be assumed to have an EPR above 430v and the plant will be classified as 'hot'. *This requirement also applies where the normal feed is via underground cable but the alternative includes some overhead line.*

5. EARTH ELECTRODE VALUE

The maximum earth electrode value will be 20Ω .

Where surge arresters are provided the maximum earth electrode value will be 10Ω .

If you cannot achieve the above values you must to seek advice from the East Midland Electricity Equipment Specialist.

6. STANDARD MATERIALS

Material	Commodity Code
50 mm ² bare copper wire	802 305
50 mm ² PVC covered copper wire	807 815
5/8 Copperbond Earth Rod	235 604
Copperbond Earth Rod Non-Extensible	235 605
5/8 Rod Coupling	235 606
5/8 Driving Stud	235 607
Leading Rod Fs21	235 608
Tip Hardened Steel Fs11	235 609
Extension Rod Fs31	235 610
Driving Sleeve Fs-2c	235 611
Clamp- Earth Rod To Cable	235 612
Phosphor bronze earth clamp	235 612

7. CONNECTIONS

You will use, where practicable, exothermic weld connections in preference to the other types of approved connectors, as they give a better electrical connection.

Underground mechanical and compression joints **shall not be sealed with waterproofing tape** (e.g. Denso tape). Experience has shown that this tends to trap moisture and accelerates corrosion.

TABLE 1. APPROVED TYPES OF CONNECTION

Connection Type	Compression Lug	Phosphor Bronze Clamp	Copper 'C' Crimp	Exothermic Weld
Conductor to rods	✗	✓	✗	✓
Conductor to conductor	✗	✗	✓	✓
Conductor to fence	✓	✗	✗	✗
Connection to main earth bar or transformer bushing	✓	✗	✗	✗
Connection to Padmount 70mm ² earth bus	✗	✗	✓	✓

8. RECOMMENDED TEST EQUIPMENT

There are two main tests to be carried out when designing and installing an earth electrode system for a distribution network.

1. Soil resistivity test
2. Electrode resistance test

Test instruments fall into three categories:

1. Three terminal – these will only measure electrode resistance
2. Four terminal - these will measure both electrode resistance and soil resistivity
3. Clamp type – these measure electrode resistance in multiply earthed systems only.

It is important to recognise, as noted in the lists, that some instruments are not accurate enough for measuring the electrode resistance of large area substation electrodes.

TABLE 1. RECOMMENDED TEST EQUIPMENT

Electrode Resistance (three terminal or clamp)	Soil Resistivity (four terminal)	Manufacturer	Model	Notes
✓	✗	Chauvin Arnoux	C.A.6423	Small area electrodes only
✓	✗	Chauvin Arnoux	C.A.6411	Clamp type, good for maintenance checks. Can only be used on multiple earthed systems.
✓	✓	Chauvin Arnoux	C.A. 6425	Small area electrode resistance only
✓	✓	AVO (Megger)	DET 5/4	Small area electrode resistance only
✓	✓	AVO (Megger)	DET 2/2	Suitable for large area electrodes

9. METHOD

The tables in this document provide guidance to help you predict the number of earth rods required for commonly encountered values of soil resistivity. At high values of soil resistivity you will need to consult the East Midland Electricity Equipment Specialist for advice.

By establishing the soil resistivity at the project planning stage you will be able to predict the amount of earthing work required prior to ordering materials and costing the excavation work. Soil resistivity can be established by on-site tests or by local knowledge combined with geological data.

By doing this you should have few, if any, surprises during installation.

9.1 How to Select Standard Electrode Systems

The following tables show the predicted earth electrode configuration to be installed to obtain the specified earth electrode values in relation to soil resistivity. Occasionally, additional electrodes may have to be installed depending on the exact nature of the soil structure.

- Step 1 Establish the Soil Resistivity – see **Section E3 - Soil Resistivity Measurements**
- Step 2 Install the HV & LV earthing systems according to guidelines below
- Step 3 Test the earth resistances - see **Section E4 - Earth Electrode Resistance Test**
- Step 4 Install additional electrodes if resistance is too high
- Step 5 Record the soil resistivity and electrode resistance values together with the type of standard earthing system used on the Diagram Amendment Card for inclusion in the Asset Repository

9.2 Assumptions

The numbers of earth rods and HV/LV earth electrode separation distances shown in these standard earthing systems have been calculated using general assumptions about the soil resistivity and structure. In order to 'fail safe' the values have taken into account fairly poor conditions. These may result in more rods and greater separation distances than would result from the more favourable soil structure at an individual site.

9.2.1 Urban networks –'Global Earthing System'

Urban networks generally comprise of an extensive network of earth electrodes and metallic sheathed cables. Together these form a large area earth electrode in their own right which provides a low resistance to earth even in high resistivity soils. This type of system is referred to as a 'Global Earthing System'

It is often difficult or impossible to make meaningful soil resistivity measurements in urban areas due to the existence of paved surfaces and numerous underground metallic objects.

For the purposes of this manual East Midlands Electricity defines a **Global Earthing System** as any urban or suburban network comprising of mainly metallic sheathed cables which has an area **greater than 10km²**. You may assume that a Global Earthing System has a **nominal soil resistivity of 150 Ω m**. However, you must still check that the new HV earth nest is less than 20 ohms before it is connected to the network using test method D in 'E3 - Soil resistivity Measurements' which compares the new HV earth electrode with the existing Global system.

9.2.2 Number of rods

Normally you should install the number of rods shown unless space is limited and the required resistance can be reached with less rods. In exceptional cases you may have to install more rods than shown if the soil structure is worse than the one assumed in the calculations.

9.2.3 Deep earths

Where deep earths are installed on pole mounted equipment it may be possible to drive the earth much deeper than the 5m minimum and therefore attain a lower earth resistance. In this case some or even all the additional rods may not be required to reach 10 ohms.

9.2.4 HV/LV separation distances

On some jobs you may find that the HV/LV separation distances are too big for the size of the site. In these cases it may be worth the effort of directly measuring the 430 volt hot zone contour of the HV earth electrode. The LV electrodes can then be placed just outside the actual 430v contour.

This test is a variation on the Three Terminal Fall of Potential Test and can be carried out when you test the HV electrode. Details can be found in Section 3 of E4 'Earth Electrode Resistance Test'

10. STANDARD EARTH ELECTRODE SYSTEMS

The following standard earthing systems are included:

- 10.1 Ground Mounted Substation 'Cold' Site
- 10.2 Ground Mounted Substation 'Hot' Site
- 10.3 Pole Mounted Transformer 'Hot' Site
- 10.4 33kV or 11 kV O/H Line Terminal Pole and Cable 'Hot' Site
- 10.5 33kV or 11kV Air Break Switch Disconnecter 'Hot' Site
- 10.6 33kV or 11kV Remote Control Auto Recloser 'Hot' Site

10.1 Ground Mounted Substation 'Cold' Site

Supplied from an Underground cable network with no O/H Line sections inserted between the substations and the Primary/Grid Substation.

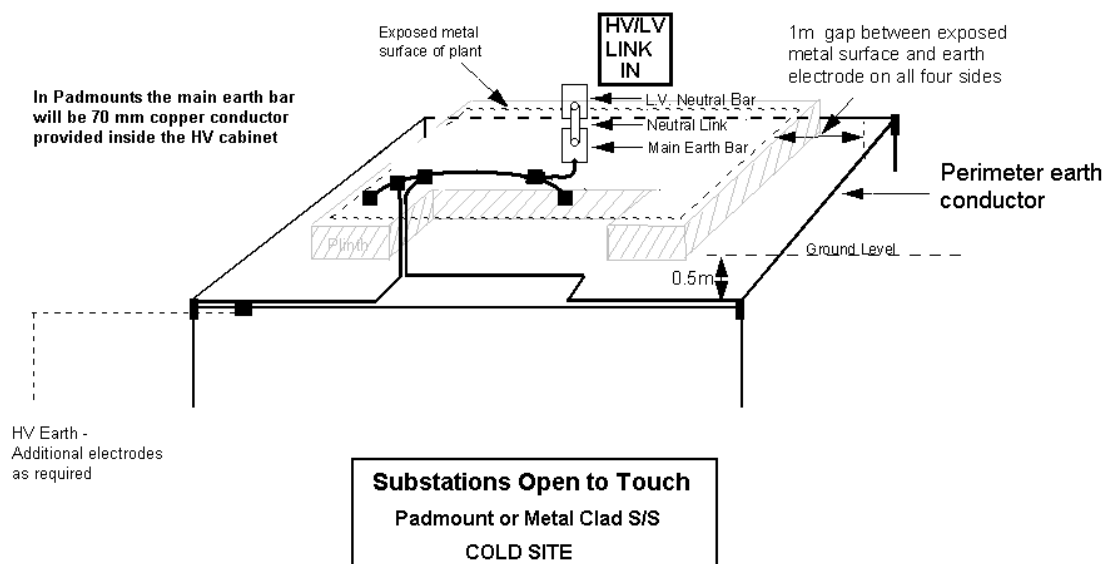
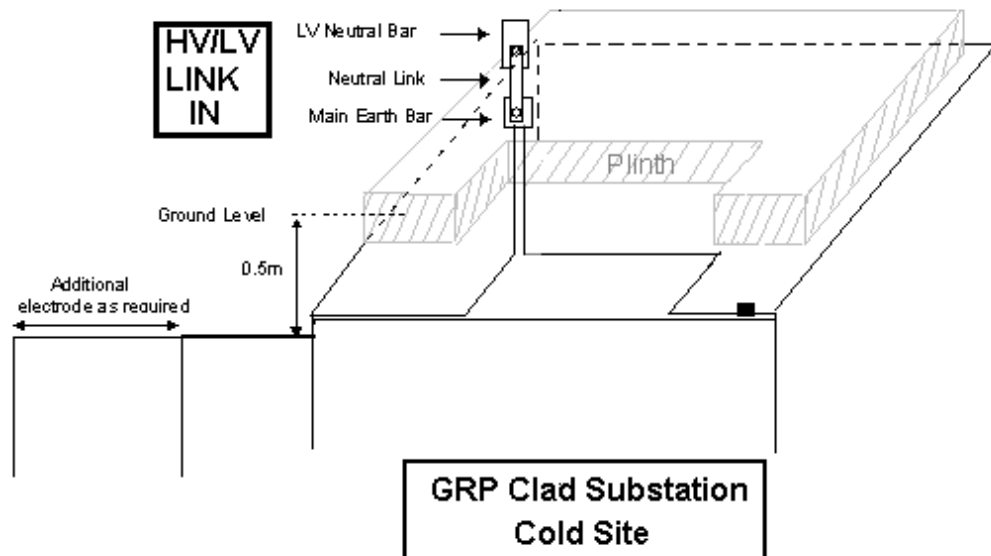
EPR Below 430v COLD	HV Earth 20 Ω Resistance		LV Earth 20 Ω Resistance	
Soil Resistivity Ω m	Basic earth No / size of rods	Additional electrodes No. of 2.4m Rods Spaced 3.6m Apart	Separate LV Earth NOT REQUIRED	
1-51	4 x 1.2m	0		
52 - 125	4 x 1.2m	0		
126 - 180	4 x 2.4m	0		
181 - 230	4 x 2.4m	1 rod		
231 - 280	4 x 2.4m	2 rods		
281 - 325	4 x 2.4m	3 rods		
326 - 370	4 x 2.4m	4 rods		
371 - 415	4 x 2.4m	5 rods		
416 - 455	4 x 2.4m	6 rods		
456 - 495	4 x 2.4m	7 rods		
496 - 535	4 x 2.4m	8 rods		
>535	Special Design			

The Basic Earth is either:

GRP Clad Compact Unit S/S – 2 rods at front, 2 rods inside through the plinth

or

Padmount Transformer or Metal Clad Compact Unit S/S – 4 rods and an Earth Perimeter Conductor placed 1 metre out around the plinth.

SSE1-COLD

10.2 Ground Mounted Substation 'Hot' Site

Supplied from a mixed O/H & U/G 11kv network

EPR Above 430v HOT	HV Earth 20Ω Resistance		LV Earth 20Ω Resistance	
Soil Resistivity Ω/m	Basic earth No / size of rods	Additional electrodes No. of 2.4m Rods Spaced 3.6m Apart	No. of 2.4m Rods Spaced 3.6m Apart	Separation Between HV & LV
1-51	4 x 1.2m	0	1 rod	5 m
52 - 125	4 x 1.2m	0	2 rods	12 m
126 - 180	4 x 2.4m	0	3 rods	17 m
181 - 230	4 x 2.4m	1 rod	4 rods	22 m
231 - 280	4 x 2.4m	2 rods	5 rods	25 m *
281 - 325	4 x 2.4m	3 rods	6 rods	25 m *
326 - 370	4 x 2.4m	4 rods	7 rods	25 m *
371 - 415	4 x 2.4m	5 rods	8 rods	25 m *
416 - 455	4 x 2.4m	6 rods	9 rods	25 m *
456 - 495	4 x 2.4m	7 rods	10 rods	25 m *
496 - 535	4 x 2.4m	8 rods	11 rods	25 m *
>535	Special Design			

The Basic Earth is either:

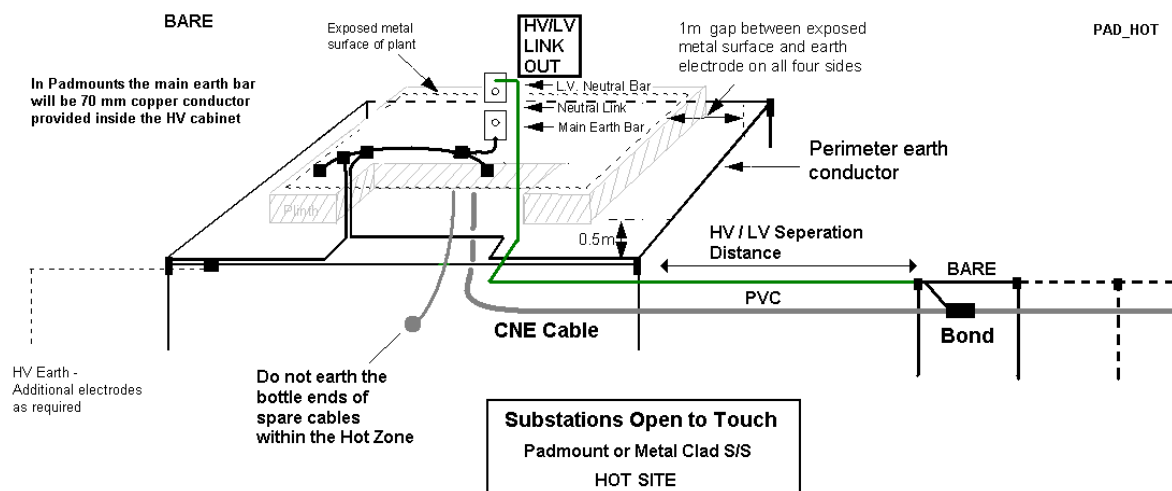
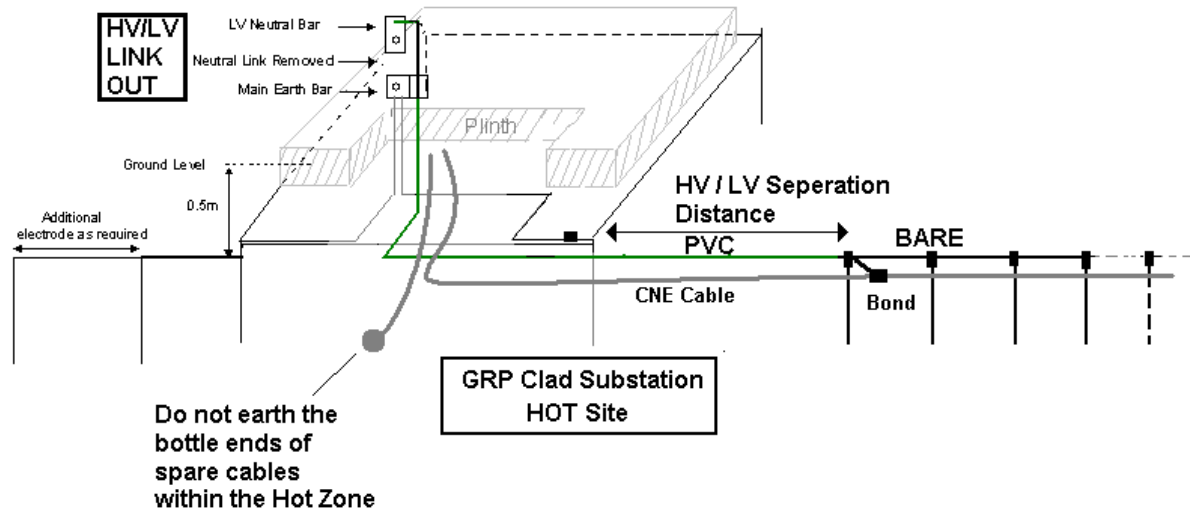
GRP Clad Compact Unit S/S – 2 rods at front, 2 rods inside through the plinth

or

Padmount Transformer or Metal Clad Compact Unit S/S – 4 rods and an Earth Perimeter Conductor placed 1 metre out around the plinth.

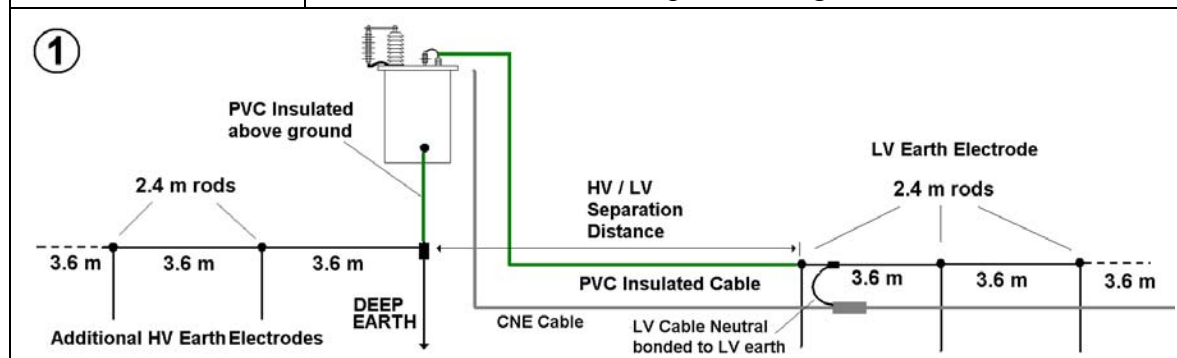
- The HV-LV separation distance should be greater than 25m at higher soil resistivities. However, it is impractical to maintain such separation distances as houses and street furniture will be erected near to the substation.

SSE1-HOT

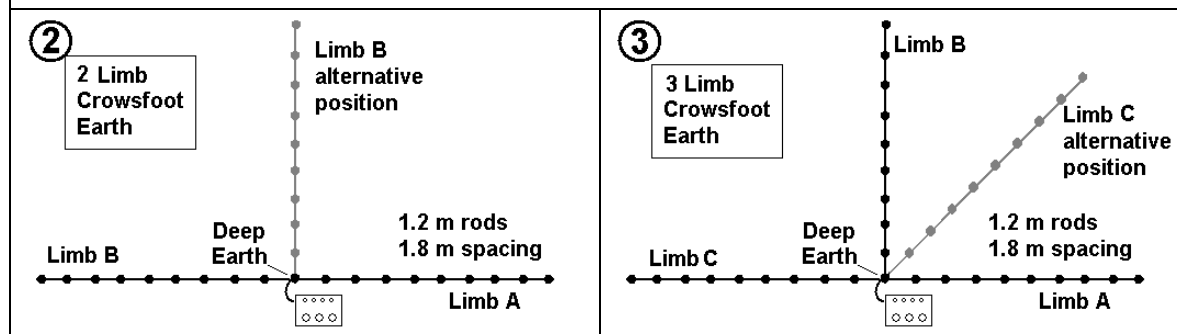


10.3 Pole Mounted Transformer 'Hot' Site

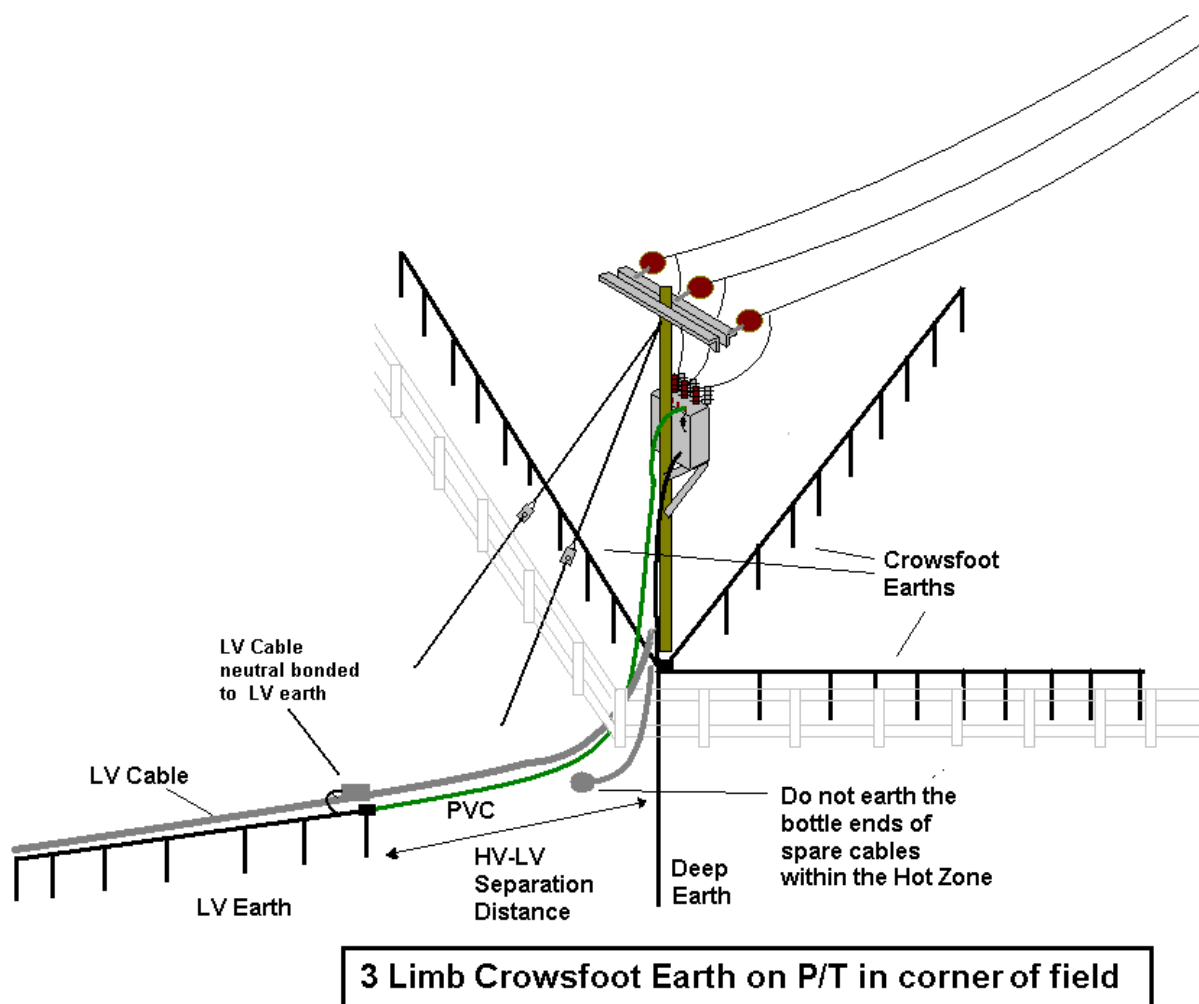
EPR Above 430v HOT	HV Earth 10 Ω Resistance		LV Earth 20 Ω Resistance	
Soil Resistivity Ω/m	Basic earth	Additional electrodes If deep earth alone cannot get 10 Ω	No. of 2.4m Rods Spaced 3.6m Apart	Separation Between HV & LV
1-24	Deep earth	0	1 rod	4 m
25-59	"	1 x 2.4m ①	2 rods	9 m
60 – 89	"	2 x 2.4m ①	2 rods	14 m
90 – 114	"	3 x 2.4m ①	2 rods	19 m
115 – 139	"	4 x 2.4m ①	3 rods	23 m
140 – 164	"	5 x 2.4m ①	3 rods	27 m
165 – 184	"	2 x 7 x 1.2m ②	4 rods	30 m
185 – 204	"	2 x 9 x 1.2m ②	4 rods	34 m
205 – 225	"	3 x 8 x 1.2m ③	4 rods	37 m
226 – 269	"	3 x 9 1.2m ③	5 rods	43 m
>270	Special Design			



At high soil resistivities earth systems over 20m long create a high impedance to lightning. The systems marked ② & ③ are 'crowsfoot' earths which limit the length of the earth to 18m by splitting the system into 2 or 3 legs set at angles to each other. 1.2m rods are used because long rods are difficult to install in high resistivity ground e.g. stone and rock.

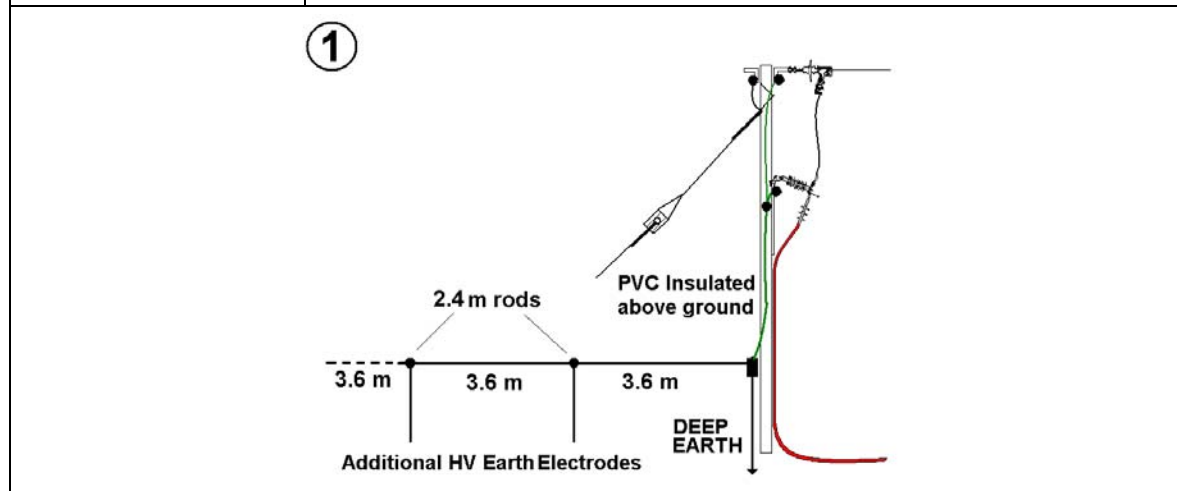


The Basic Earth is: A Deep Earth driven in at least 3 metres

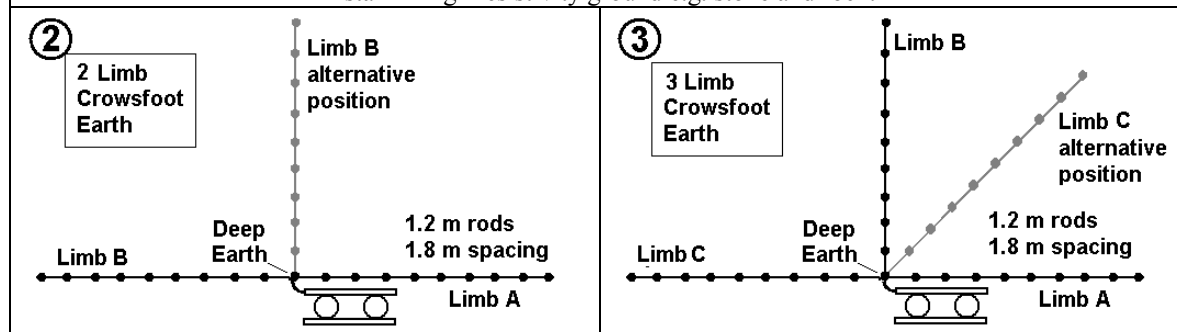


10.4 33kV or 11 kV O/H Line Terminal Pole and Cable 'Hot' Site

EPR Above 430v HOT	HV Earth 10 Ω Resistance		LV Earth 20 Ω Resistance	
Soil Resistivity Ω/m	Basic earth	Additional electrodes If deep earth alone cannot get 10 Ω	Separate LV Earth NOT REQUIRED	
1-24	Deep earth	0		
25-59	"	1 x 2.4m ①		
60 – 89	"	2 x 2.4m ①		
90 – 114	"	3 x 2.4m ①		
115 – 139	"	4 x 2.4m ①		
140 – 164	"	5 x 2.4m ①		
165 – 184	"	2 x 7 x 1.2m ②		
185 – 204	"	2 x 9 x 1.2m ②		
205 – 225	"	3 x 8 x 1.2m ③		
226 – 269	"	3 x 9 1.2m ③		
>270	Special Design			



At high soil resistivities earth systems over 20m long create a high impedance to lightning. The systems marked ② & ③ are 'crowsfoot' earths which limit the length of the earth to 18m by splitting the system into 2 or 3 legs set at angles to each other. 1.2m rods are used because long rods are difficult to install in high resistivity ground e.g. stone and rock.



The Basic Earth is: A Deep Earth driven in at least 3 metres

10.5 33kV or 11kV Air Break Switch Disconnecter 'Hot' Site

EPR Above 430v HOT	HV Earth 20 Ω Resistance		LV Earth 20 Ω Resistance	
Soil Resistivity Ω/m	Basic earth 2.4m rod	Additional electrodes No. of 2.4m Rods Spaced 3.6m Apart	LV Earth NOT REQUIRED	
1-24	1 rod	-		
25-114	1 rod	1 rod		
115 – 164	1 rod	2 rods		
165 – 225	1 rod	3 rods		
226 – 269	1 rod	4 rods		
>270	Special Design			

Diagram illustrating the special design for soil resistivity >270 Ω/m . The design shows a plan view and a cross-section of the grounding system.

Plan View: Shows a 50mm² PVC conductor with a 300mm diameter loop, spaced 1m apart, with a total length of 5m. The conductor is labeled "50mm² PVC" and "d = 300mm APPROX".

Cross-section: Shows the conductor buried 100mm deep in granite chippings. The conductor is labeled "BARE 50 mm² COPPER CONDUCTOR" and "BARE 50 mm² HDC CONDUCTOR". The chippings are labeled "100mm GRANITE CHIPPINGS" and "300mm MAX.". The handle is labeled "ABSD HANDLE" and "INSULATED INSERT".

The Basic Earth is:

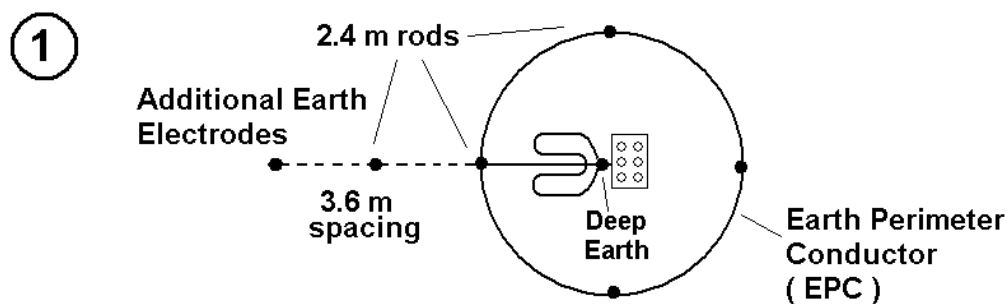
A single 2.4m rod driven in 5m from the base of the pole on the opposite side from the operating handle connected to the ABSD steelwork by 50 mm² PVC insulated copper cable.

plus

A separate earth mat connected to the handle made of 50mm² bare copper cable

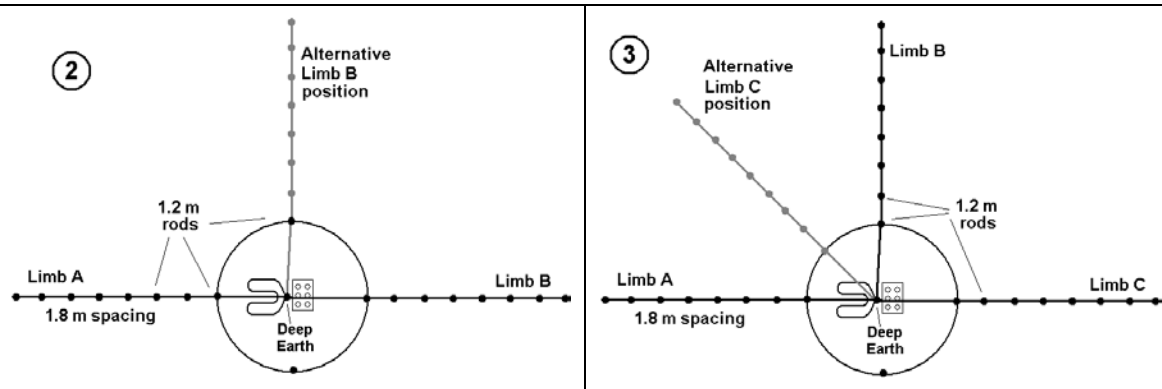
10.6 33 kV or 11 kV Remote Control Pole Mounted Recloser 'Hot' Site

EPR Above 430v HOT	HV Earth 10 Ω Resistance		LV Earth 20 Ω Resistance	
Soil Resistivity Ω/m	Basic earth	Additional electrodes	Separate LV Earth NOT REQUIRED	
1-114	Deep earth + 4 rods + EPC	0 ①		
115 – 139	“	1 x 2.4m ①		
140 – 164	“	2 x 2.4m ①		
165 – 184	“	2 x 5 x 1.2m ②		
185 – 204	“	2 x 7 x 1.2m ②		
205 – 225	“	3 x 7 x 1.2m ③		
226 – 269	“	3 x 8 x 1.2m ③		
>270	Special Design			



At high soil resistivities earth systems over 20m long create a high impedance to lightning.

The systems marked ② & ③ are 'crowsfoot' earths which limit the length of the earth to 18m by splitting the system into 2 or 3 legs set at angles to each other. 1.2m rods are used because long rods are difficult to install in high resistivity ground e.g. stone and rock.

**The Basic Earth is:**

A Deep Earth driven in at least 3 metres plus four rods and an Earth Perimeter Conductor placed at a radius of 2 metres around the Recloser.

plus

A separate earth mat connected to the control box made of 50mm² bare copper cable

11. HV and LV Electrode Separation Distances

Whenever there is any overhead line in the circuit between an item of plant and the Primary Substation you cannot guarantee that the Equipment Potential Rise will be below 430 volts.

Therefore the HV and LV earthing systems of plant must be separated to avoid dangerous potentials being transferred onto the LV neutral under HV earth fault conditions.

The separation distance between the HV and LV electrodes depends on the soil resistivity and the physical size of the HV electrode system. The higher the soil resistivity the greater the separation.

Also a 10Ω HV electrode system will require a greater HV/LV separation than a 20Ω HV electrode system due to its larger size.

Where ground mounted substations are installed in high soil resistivity areas the theoretical separation distance may be greater than 50 metres. This is normally impractical because houses and street furniture will invariably be erected within this zone. However, because substations are connected to at least one other earth (e.g. a terminal pole or another substation) the Equipment Potential Rise will be reduced. Therefore this specification limits the separation distance to 25 metres for ground mounted plant.

Pole transformers on the other hand are normally connected to a single HV earth. Full separation is required. Pole transformers should normally be sited well clear of houses and this allows full separation to be achieved.

On overhead LV systems sufficient separation can be maintained by earthing the LV neutral one span away from the transformer.

Where the LV is underground the neutral can be connected to earth using either of the following methods:

(a) Preferred Method

Connect the transformer neutral to the LV earth electrode, positioned at the correct separation distance, using insulated conductor laid alongside the LV cable in the trench.

Additionally the LV electrode should be bonded to the LV cable neutral earth at the first earth rod. This is to safeguard against third party damage to the insulated LV earth conductor causing complete loss of the LV earth. *This bond has been added because of the increased HV/LV segregation distances place this conductor at greater risk than the 3m separation used in previous specifications.*

(b) Exceptional Method

If a short length of cable is being laid, for example to joint in a transformer into an existing LV network, there may not be sufficient trench to extend the insulated neutral to the required separation distance.

It is not desirable to lay a long length of insulated neutral conductor as it is exposed to theft or damage where it is not laid alongside an obvious electric cable.

Therefore, excavate the existing LV cable at the required separation distance along

the LV cable and joint the cable's neutral/earth to the LV earth electrode.

No customers are to be connected between the transformer and this earth electrode joint. It is important to ensure this position is recorded on the relevant plans and the Geographical Information System (GIS).

12. Bottle ends and joints within the hot zone

It is good practice to install spare cables into feeder pillars and to bottle end them just outside the substation. This enables additional cables to be jointed on at a later date without having to make the LV pillar dead.

Be aware that the standard bottle end has a PME earth electrode as part of the kit. **This PME earth must not be installed** if the bottle end is inside the HV/LV separation distance (Hot Zone).

You can 'de-earth' a standard bottle end kit by omitting the 16mm² earth lead and then sealing the open end of the joint using a suitable cable cap. (We are arranging to have future bottle end kits supplied with a blanking off plug).

Straight and breech joints may also have PME earth electrodes in future. If you are connecting a new cable to a bottle end that you suspect may be within the hot zone **then do not use the earth electrode** supplied with the kit. If you are not sure how big the Hot Zone is then assume it is 25 metres for a ground mounted substation and 50m for a pole transformer.

Section E6

Protective Multiple Earthing

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Version	Prepared by	Approved by	Issue Date
2	Tony Haggis	Tony Haggis	Jan 2002

Revision Log For Section E6 Protective Multiple Earthing

Changes made in version 1 Feb 2001

Section	Notes about the change
E6	First Issue

Changes made in version 2 Jan 2002

Section	Notes about the change
1.11	European Naming of Earthing Systems – additional section
3.2.19	Cell Phone Base Stations on 132, 275 or 400 kV Towers – additional section
3.2.21	Multiple Services to Steel Framed Buildings – restriction on the use of PME - additional section
FIG.11.	Supplies to Equipment Mounted on Electricity Towers and Communication Masts – Superseded by ER G78

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1. APPLICATION OF PROTECTIVE MULTIPLE EARTHING

1.1 General

This document sets out the requirements for new and existing LV networks to enable the use of Protective Multiple Earthing (PME).

1.2 Substation Earthing

In HV/LV substations feeding PME networks the rise of earth potential on the neutral/earth shall not exceed 430 volts during an earth fault in the high voltage system. In practice this means that on urban networks that have a continuous metallic sheath, insulated or non-insulated, back to the source transformer, the voltage rise will be below 430v. This means that the low voltage neutral is to be connected directly to the high voltage earth electrode.

Where there is no continuous metallic return back to source, for example on the overhead network or isolated underground network, the voltage rise will exceed 430v. This means that the low voltage neutral has to be connected to a separate earth electrode that is outside the influence of the high voltage earth electrode.

For more details see the relevant sections of the Earthing Manual:

Section E2 Earthing Guidance Notes - Introduction and Definitions

Section E5 - Distribution Standard Earthing Layouts

Section E10 - Hot Zone Guidance Notes

1.3 Supply Neutral Conductor

In view of the importance of avoiding the possibility of an open circuit in the supply neutral conductor, it is essential to pay particular attention to its integrity through the design, construction, maintenance and operation of the distribution system.

Compression joints, duplicate connectors or other approved joints shall be used on overhead lines at all points of connection between copper neutral conductors, e.g. at section poles and at service connections.

Where the supply neutral conductor is aluminium, compression joints only should be used except on aerial bundled conductor where connectors satisfying Electricity Association Technical Specification 43-14 shall be permitted.

On underground cable networks, the design of cables, joints and terminations shall be such as to minimise the risk of an open circuit of the neutral.

The supply neutral conductor shall not be less than half the cross sectional area of the phase conductors, with the exception of single phase two wire conductors, in which the cross-sectional area of the supply neutral shall be not less than that of the phase conductor.

No fusible cut-out, circuit breaker or switch shall be included in the supply neutral conductor, except:

- When agreed with the Network Asset Manager under an agreement for the connection of low voltage generating plant in accordance with Electricity Supply Regulation 26.
- For the protection low voltage static balancers (interconnected star balancing transformers) where the neutral lead to the balancer may be fused.

1.4 Earthing of Supply Neutral Conductor of LV Distributors

The resistance of the supply neutral conductor to the general mass of earth shall not at any point exceed 20 ohms. This will be ensured by installing the substation earth to the current specification which requires a maximum value of 20 ohm at the substation.

In addition to the LV neutral earth at or near the substation, the supply neutral conductor shall also be connected to additional earth electrodes (PME Earths) or to the supply neutral conductor of another distributing main (i.e. through a link box or inter-connector):

- A PME Earth shall be installed on each main or branch cable. Normally the PME Earth will be at the end of the cable. Where existing SNE cables are converted to supply some PME services the PME Earth need not be at the cable end. However, it shall not be nearer to the substation than the most remote service having a PME earthing terminal.
- A PME Earth shall be installed at each joint position where all the cables to be jointed have insulated sheaths.
- A PME Earth may be installed at a service cut-out. The customer's earthed metalwork, gas and water service pipes **shall not** be used as an earth rod.

See Fig.1. for the application of PME Earths.

1.5 Underground Cable Networks

Where PME facilities are available to customers, the following requirements apply when combined neutral and earth (CNE) cables are incorporated into networks containing cables with separate neutral and earthing conductors (SNE cables). Additional requirements are given in clause 2.1 for networks where SNE earth terminals have previously been provided to existing customers.

CNE cables shall be used for reinforcement, diversions, and repairs to existing SNE systems. The neutral to sheath bonding and neutral earthing requirements of such systems will comply with section 1.4 and any additional requirements shown in Fig.2.

A PME Earth shall be provided at the end of the section of CNE cable most remote from the distribution substation. The neutral of each section of CNE cable shall be bonded to the neutral/sheath of the adjacent SNE cable. The whole of the distributor between the substation and this PME Earth will then be suitable for providing PME.

The remote sections of SNE distributors can be converted to PME by bonding the neutral and sheath to a PME Earth at the end of the SNE distributor.

When a new CNE service cable is installed or used to replace an existing SNE service cable on a SNE main, the customer may be offered PME facilities provided that a PME Earth is connected to the neutral at the service joint.

1.6 Overhead Networks

The principles applied in PME underground systems also apply to overhead systems or mixed overhead and underground PME systems.

When converting 3 phase 4 wire systems to PME, all overhead sections of associated main and any other main likely to be used as an alternative supply, between the supply substation and the connection to the customer being offered PME, shall meet the requirements of this document.

PME Earths shall be installed at intervals not greater than 8 spans.

On poles supporting cable terminations, the sheaths and metallic termination boxes shall be bonded to the neutral conductor.

Undereaves wiring should be considered as a main or branch and not as a service.

1.7 Type of Earth Electrodes

Earth electrodes will be either:

- Copper bonded rods with a minimum diameter of 14mm, driven vertically into the ground.
- Hard drawn copper conductor or tape with a minimum cross-sectional area of 50mm² laid horizontally in the joint hole or cable trench.
- If several driven rods are used to form an electrode system the distance between them will not be less than 1.5 times the depth to which the rods are driven.

1.8 Values of Earth Electrode Resistance

The resistance of Substation HV and LV electrodes shall each be less than 20 ohms. This value will ensure the operation of HV protection under fault conditions.

The resistance of the earth electrodes at the substation shall be measured before being connected to the supply neutral conductor and HV/LV metalwork.

PME Earths shall be less than a nominal value of 100 ohms. A resistance test is not required.

1.9 Type and Size of Earth Connections

Where aluminium connections are used both the conductor and the joint to the earth electrode must be adequately protected against corrosion.

The minimum size of earthing and bonding connections shall be as follows, all refer to copper or copper equivalent conductors:

TABLE 1. Type and Size of Earth Connections

Substation Earth lead to rod HV	50 mm ² Bare
Substation Earth lead to rod LV	50 mm ² Insulated
PME Earth lead to earth rod	16 mm ² Insulated
Bonding connections between the neutral busbar to the earth busbar at a substation	Half the current (where appropriate) carrying capacity of the largest phase conductor in the distributor
Bonding connections to link boxes and network feeder pillars (where applicable)	16mm ²
At customer's premises, connection between service neutral and Company's earthing terminal	16mm ² or half the size of the company's neutral meter tail whichever is the larger
Connection between sheath of SNE cable and neutral of CNE cable.	16mm ² for services & 50mm ² for distributors
At customer's premises the main equipotential bonding conductor from the company's earthing terminal	See BS7671: Electrical Installations of Buildings

TABLE 2. Approved Methods of Connection

Connection Type	Approved Mechanical Clamp	Phosphor Bronze Clamp	Copper 'C' Crimp	Exothermic Weld
Earth lead conductor to rods	✗	✓	✗	✓
Neutral and earth of cable to main earth conductor	✓	✗	✗	✗
Earth lead to earth lead	✗	✗	✓	✓

1.10 Insulation of Neutral Earthing Leads

Except at ground mounted substations with combined HV metalwork and LV system earths the LV neutral earthing leads shall be insulated with PVC or XLPE of minimum thickness 0.8mm or equivalent.

1.11 European Naming of Earthing Systems

Mains electricity systems are categorised in the many European countries according to how the earthing is implemented. The common ones are TN-S, TN-C-S and TT.

Note that in these descriptions, 'system' includes both the supply and the installation, and 'live parts' includes the neutral conductor. These conventions are used in BS 7671 Requirements for Electrical Installations (IEE Wiring Regulations 16th edition)

Description of letters

First letter: (refers to the supply network)

- T - The live parts in the system have one or more direct connections to earth (i.e. via the neutral).
- I - The live parts in the system have no connection to earth or are connected only through a high impedance.

Second letter: (refers to the customer's installation)

- T - All exposed conductive parts are connected via earth conductors to a local earth connection.
- N - All exposed conductive parts are connected to the earth provided by the supply network.

Remaining letter(s):

- C - Combined neutral and protective earth functions (same conductor).
- S - Separate neutral and protective earth functions (separate conductors).

Valid system types in the BS 7671 (16th Edition IEE regs):

- TN-C** No separate earth conductors anywhere - neutral used as earth throughout supply and installation (**not used in UK**).

- TN-S** The supply network provides a separate earth conductor back to the substation i.e. traditional lead covered cables.
- TN-C-S** [Protective Multiple Earthing] Supply cables combines the neutral and earth in same conductor, but they are separated out in the installation.
- TT** No earth provided by the supply network, the installation requires it's own earth rod and Residual Current Device (common with traditional overhead supply lines).
- IT** Supply is e.g. portable generator with no earth connection, installation provides own earth rod.

Note that the letters used in the European Standards are derived from the French language:

- T – Terre - Earth
- N – Neutre – Neutral
- S – Séparé - Separate
- C – Combiné – Combined
- I – Isolé – Insulated

2. CUSTOMERS' INSTALLATIONS

2.1 General

Where customers' installations use SNE earth terminals all reasonable precautions shall be taken to ensure that the safety of these customers is not adversely affected by repairs, modifications or additions to existing networks.

Where CNE cable is introduced into SNE networks existing SNE customers' installations may retain an SNE earth provided:

1. a continuous metallic return path exists to the source substation
and
2. they are connected to a length of electrically continuous non-insulated metallic sheath cable, sufficient to limit the rise of potential under open circuit neutral conditions. This criteria will be met provided the resistance to earth of the metallic sheath is 10 ohms or less (see Table 3).

TABLE 3 Resistance to Earth of Un-insulated Sheathed Cables

Soil Type (indicative)	Resistivity (Ω/M)	Minimum Length of Cable (M) to Achieve a Resistance to Earth of 10Ω
Loam/Silt	25	5
Clay	50	7
Chalk, Marls	100	16
Peat, Marsh	200	40
Sand	300	60
Slates, Shale, Rock	400	85

If these conditions cannot be met there should be discussions with the existing SNE customers. The customers have the option of:

- converting to PME (provided their bonding complies with BS7671: Electrical Installations of Buildings)
- or
- retain a SNE supply but with earth fault protection may be provided by an Residual Current Device.

The cost of converting to PME or installing a Residual Current Device is born by the customer who is responsible for providing and maintaining effective earth fault protection the premises.

Alternatively, SNE earths may be maintained by running a separate earth cable along with the section of CNE cable. Where this option is chosen the neutral and earth should be so constructed as to minimise the risk of deterioration or damage (See Fig.12).

2.2 Earthing Terminal

The Customer's earthing terminal shall be connected to the supply neutral conductor at the service position by either a copper conductor with a minimum cross-sectional area as specified in Table 1 or a cut-out incorporating an integral earthing terminal. Any bolted link between the neutral and the earthing terminal shall be of equivalent cross-sectional area.

The metallic sheath and armouring of underground service cables shall be connected to the earthing terminal, neutral terminal or neutral connector block as appropriate, by means of a copper conductor of minimum cross-sectional area as specified in Table 1. The connection to the cable sheath should be made by means of either an earthing clamp complying with the tests specified in BS951 Earthing Clamps, or a substantial soldered connection.

Where service cables with a concentric neutral are used, the concentric neutral and any separate earth conductor (which must be included in the cable) shall be connected to the earthing terminal, neutral terminal or neutral connector block, as appropriate.

2.3 Bonding of Metalwork

Before a PME terminal is provided, the customer shall install main equipotential bonding as part of their installation in accordance with BS 7671.

2.4 Customer's Service Polarity Testing

It is required that a polarity test is carried prior to and following the connection of a customer's installation. **This test is to be carried out in accordance with the Local Management Instruction "Polarity & Phase Rotation Testing".**

NOTE: If the live and neutral conductors are crossed on a PME service, a dangerous situation could arise in that the customer's metalwork becomes live at line voltage. In these circumstances the earth in the vicinity of the premises also tends to rise to line voltage and tests intended to establish polarity using neon testers may be misleading, indicating correct polarity even though it is reversed.

2.5 Labels and Notices

Skilled or instructed persons expected to work in connection with networks where PME has been applied shall be provided with instructions that Neutral links in such systems should not normally be removed.

Where PME facilities are available to a customer, a label shall be affixed at the service position drawing attention to the fact that the service is connected to a network having Protective Multiple Earthing.

3. SPECIAL SITUATIONS

3.1 General

A PME earthing terminal provides a very satisfactory means of protection for the majority of installations. However, there are a number of special situations where the customer should provide an additional or alternative form of earth-fault protection such as that provided by an earth electrode and a suitably rated and installed Residual Current Device.

Where the use of PME is precluded in any customer's installation or part thereof an independent earthing system associated with the use of a Residual Current Device or other protection must be segregated from any metalwork associated with the PME system.

NOTE: Specific guidance on various specialised installations can be found in BS 7671.

3.2 Consideration of Special Situations

3.2.1 Railway Electric Traction Systems

A PME terminal shall not be provided to premises that are adjacent to or supplying electric traction systems. The customer is to provide a separate earth terminal and appropriate protection in compliance with BS 7671.

3.2.2 Construction Sites

It is usually impracticable to comply with the bonding requirements of the Electricity Supply Regulations on construction sites and a PME earthing terminal should not be provided. For large temporary supplies which require their own substation it will usually be possible to provide an earthing terminal connected directly to the transformer neutral. For detailed requirements BS 7375 and BS 7671 should be consulted.

3.2.3 Supplies to Temporary Buildings (not associated with construction sites)

A temporary building may be treated in the same manner as a permanent building and provided with a PME earthing terminal provided that:

- the building is constructed so that a person in contact with the general mass of earth cannot touch any metalwork of the temporary building which would be connected to a PME earthing terminal
- and
- the installation complies with the PME requirements of BS 7671.

A temporary buildings which is not constructed as above (e.g. metal-clad buildings) should be treated in the same way as a caravan under 3.2.6 below.

3.2.4 Farms and Horticultural Premises

Where all extraneous conductive parts in remote buildings cannot be bonded to the earthing terminal, the pipes and metalwork of isolated buildings, whether or not they have an electricity

supply, shall be segregated from metalwork connected to the PME earthing terminal. Any supplies to such buildings should be controlled by a Residual Current Device and the associated earth electrode and protective conductor shall be segregated from any metalwork connected to the PME earthing terminal.

Where segregation is not possible then the alternative of using suitable earth electrodes and rods for the whole of the installation should be considered. Alternatively if a dedicated transformer is used to supply the premises then Protective Neutral Bonding (PNB) may be used.

Particular care must be taken in areas where livestock are housed as they are sensitive to very small voltages. A suitable metallic mesh shall be installed in the concrete bed of a dairy and bonded in accordance with the PME requirements.

If PME is to be applied to an existing dairy the steel reinforcement in the floor should be bonded. Alternatively if small voltage differences are unacceptable the area concerned should be protected by a Residual Current Device and the associated earthing system segregated electrically from the remainder of the installation.

NOTE:

If PME is to be used and the steel reinforcing mesh of the concrete cannot be bonded or does not exist the customer must be advised that in the case of dairies the small voltage differences referred to above may adversely affect livestock feeding at milking and also milk output. For details consult the current edition of BS 7671.

3.2.5 Sports Pavilions and Swimming Pools

Where no shower area exists nor is likely to exist in a Sports Pavilion, PME can be offered provided the appropriate metalwork is bonded. Where a shower exists PME shall only be applied where there is a bonded earth grid in the floor of the shower area.

Swimming pools supplied with their own dedicated service should be protected with a Residual Current Device. All metalwork shall be bonded and connected to an earth electrode.

Where a swimming pool forms part of a residence all metalwork and pipes supplying the pool shall be connected to an earth electrode and segregated from the pipes and earth conductors of the rest of the building. A Residual Current Device shall be used to protect the supplies to the pool area. Where segregation of pipes and metalwork around a pool is impracticable (e.g. an indoor pool) the installation of a metal grid around the pool and the bonding of adjacent metalwork is recommended together with a Residual Current Device in addition to PME.

3.2.6 Caravans, Boats and Marinas

The Electricity Supply Regulations preclude the provision of a PME earthing terminal to a caravan or boat. However this does not preclude a PME earthing terminal being provided for use

in permanent buildings on a caravan site such as the site owners living premises and any bars or shops. Due to the higher probability of persons being barefooted on caravan sites the extension of PME earthing to toilet and amenity blocks is not recommended.

Supplies to caravans and boats should be two wire phase and neutral supplied through a Residual Current Device which must be provided by the customer or site owner. This method of supply is also recommended for toilet or amenity blocks. An independent earth electrode is required. (see EATS 41-24, Fig.4. for the recommended method of giving a supply to a caravan site)

3.2.7 Mines and Quarries

Any supply taken to an underground shaft, or for use in the production side of a mine or quarry, must have an earthing system which is segregated from any system bonded to the PME terminal. Any supply taken to a permanent building can be given a PME terminal provided the building electrical installation wiring conforms to BS 7671. Where a mine or quarry requires a supply both to a permanent building and either an underground shaft or the production side of the quarry, precautions must be taken to ensure that these latter supplies have an earth system segregated from the PME earth system. Further details are given in HMSO publications COP 34 and COP 35.

3.2.8 Petrol Filling Stations

In accordance with current HSE Publication HS(G)41, PME facilities shall not be provided in petrol filling areas.

The filling station area should be treated as a separate system and not have its circuit protective (earthing) conductors connected to the supply neutral. Where the filling station is part of a larger site, PME facilities may be provided for permanent buildings such as restaurants and shops. provided the filling station earth is electrically segregated. Further details are shown in HS(G)41.

3.2.9 Centre-Tapped Supplies via an Isolating Transformer

A number of buildings with bar services have a 2kVA isolating transformer with a 110V Centre-tapped secondary winding to give 55V to earth. A supply is given via a flexible armoured cable to delivery tankers which are fitted with 0.7kVA pump motors.

The transformer does not however provide isolation for the centre-tap of the 110V winding if it is connected to the PME earthing terminal. A form of connection is shown in Fig.5. The risk from providing supplies outside the equipotential zone is considered to be slight particularly as the time the tanker will be connected to the supply will be short.

3.2.10 High Rise Buildings and Building Complexes

It is recognised that the provision of an end of main earth electrode could be very difficult or expensive in these situations. As an alternative, if there are several separate distributing mains, the connection together of the supply neutral conductors at their far ends will satisfy the necessary requirements of the Electricity Supply Regulations. The neutral of the smallest cable shall be not less than half the cross sectional area of the phase conductor of the largest cable. The connection shall be made using a conductor equivalent in cross-section to the neutral of the smallest distributing main and the conductor shall be identified as a neutral conductor. Particular consideration must be given to the requirements of Electricity Supply Regulation 7 as illustrated in Fig.1. of this document.

The following situations can exist:

(i) New services

The ownership and responsibility of rising and/or lateral service connections in buildings will determine the design of electrical installations. The connections may be owned (a) by the PES or (b) by the landlord, developer or customer.

a Services owned and maintained by the PES:

Supply will usually be given by CNE cable and an individual PME terminal will be offered to each customer provided the customer's installation meets the bonding requirements of BS 7671. In addition to the bonding in the customer's premises the gas, water and other services and accessible steel structures must be bonded to the main supply cable as close as possible to the point of entry into the building of these services. Fig.6. shows an example of this system.

b Services owned and maintained by the landlord, developer or customer:

(e.g. communal meter position) A PME terminal can be provided by the PES at the main electrical intake position. Within the installation the neutral conductor shall be insulated and separate from the earth conductors to all premises. Bonding of the customer's electrical installation must be in accordance with BS 7671. In addition to the bonding in the customer's premises, the gas, water and other services and accessible steel structures must be bonded to the main supply cable as close as possible to the point of entry into the building of these services. Fig. 7 shows an example of this system.

(ii) Existing Services

When PME is requested for existing customers, the following requirements will apply in all cases:

- a PME and other earthing methods must not be mixed in the same building.
- b Gas, water other metallic services and accessible steel structures must be bonded to the main earthing terminal as close as possible to their point of entry into the building.

Additional requirements for various service arrangements are as follows:

Where the rising and/or lateral services are owned and maintained by the PES, the customers' bonding requirements will depend on the type of service cable. Where SNE services incorporating adequate circuit protective conductors exist, no PME bonding will be required in individual flats but equipotential bonding to comply with BS 7671 should be present. In this case the size of the main PME bonding must correspond to the size of the incoming supply cable in accordance with BS 7671. See Fig.8. Where services have no adequate circuit protective conductor, they should be treated as CNE and PME bonding complying with BS 7671 will be required in each flat. See Fig.6.

Where the rising and/or lateral distribution circuits are owned and maintained by the landlord, developer or customers the requirements are identical to section (i)b above. PME can only be given where the distribution circuits have circuit protective conductors, the size of which should be in accordance with the current edition of BS 7671. See Fig.7.

3.2.11 Supply Terminating in a Separate Building

Occasionally a service will terminate in a position remote from the building it supplies. In this case the size of the PME bonding in the building supplied must be related to the size of the incoming supply cable in accordance with BS 7671. If the size of the earth conductor of the cable between the supply intake position and the building is less than that of the PME bonding conductor, a suitable additional conductor will have to be installed.

3.2.12 PME and Outside Water Taps

Under an open-circuit supply neutral condition the potential of an outside water tap will rise above earth potential. A person coming into contact with the tap could receive an electric shock and the shock could be severe if that person were barefooted. The probability of these two conditions occurring together is considered to be so small that the use of PME where a metal outside tap exists is not precluded by BS7671.

It is recommended however that a plastic insert be provided in the pipe to the outside water tap.

3.2.13 LV Embedded Generators

Recommendations for the connection of embedded generators are covered by Engineering Recommendation G59/1. Paragraph 5.2 of that document discusses the earthing arrangements of LV generators.

3.2.14 Street Lighting and Other Street Furniture

i General

The application of PME to street furniture is governed by the Exemption to the Electricity Supply Regulations in Appendix 3 of Engineering Recommendation G12/3.

ii Installations covered by the Exemption

Bonding conductors shall have a minimum size equal to that of the supply neutral or 6mm² copper equivalent whichever is the smaller. It should be noted that the Exemption applies both to street furniture supplied by a PES service cable or a street lighting authority when using CNE cables. In this latter case supply from the PES is usually to a pillar. See Fig.9.

iii Installations not covered by the Exemption

Private installations are not covered by the Exemption. These and local authority installations using SNE cables which are supplied from PME services must comply with Fig.10.

iv Items applicable to the installations

The following principles apply to all connections to street furniture.

Bonding of Small Isolated Metal Parts

Small isolated metal parts not likely to come into contact with exposed or extraneous parts or with earth, for example small metallic doors and door frames in concrete units, *need not be* earthed.

Earth Electrodes

All earth electrodes installed must comply with Section 1.7. It is not permissible to consider metallic street furniture to be earth electrodes.

Earthing Terminal

Until the requirements of the Exemption have been complied with the earthing terminal should be rendered electrically inaccessible so as to prevent unauthorised connection.

3.2.15 Lightning Protection Systems

For the majority of situations it is acceptable for lightning protection to be connected to the customer's earthing arrangements and thus to the PES PME Terminal, where PME is provided. Guidance on the connection of lightning protection conductors to the customer's earthing is provided in BS 6651 'Protection of Structures against Lightning'.

When periodic testing of the lightning protection system is undertaken, precautions are necessary when breaking the link between the lightning protection electrode and the customer's earth since the customer's earth may be at a potential above true earth.

3.2.16 Roadside and other Housings Accessible to the Public

- i Examples are Public Telephones, Pedestrian Crossing Bollards, Ticket Machines etc. Equipment in this type of structure should be Class II or equivalent construction. No mains-derived earthing terminal is required, neither is a residual current device needed for earth fault protection.

The service arrangement to BT public telephone housings is covered in Engineering Recommendation P04/1. It is suggested that telephone housings owned by other telephone operators should have similar service arrangements.

- ii Other free-standing structures not of Class II construction such as small brick or metal housings, or metal cabinets containing pumps, motors, controls etc., may be offered the use of a PME terminal provided the supply is single phase and the maximum load does not exceed 2kW. An earth electrode with a value not exceeding 20 ohms should be supplied and installed by the customer and connected to the earth bar.

If these conditions are not met, a PME terminal should not be offered. An independent electrode is required and a Residual Current Device should be installed.

- iii For other wall or pedestal mounted structures not of Class II construction which require a single phase supply, the use of a PME terminal should not be offered. These structures should have an independent electrode fitted and be protected by a Residual Current Device.
- iv For installations requiring three phase supplies, PME can normally be offered.
- v Crash barriers adjacent to street furniture should not be connected to a PME earth terminal.

3.2.17 Cathodic Protection Installations

The usual source of power for cathodic protection installations is a mains supplied transformer rectifier unit.

The preferred arrangement is for the customer to provide his own earthing together with an appropriate Residual Current Device. A SNE or PME earth **can** be given provided there is no electrical connection between the primary and the secondary of the transformer rectifier unit.

Where supply is given via a pole mounted transformer the substation earth electrodes and stay wires should be situated as far as possible from the ground bed.

BS 7361 gives more information on cathodic protection.

3.2.18 Small Radio Stations including Cell Phone Base Stations

Small radio stations **may be** provided with a PME terminal.

However, some radio stations require an independent earth electrode for functional purposes. Where such an earth is installed its resistance may be comparable or less than the PES earthing system and in the event of an open circuit neutral the earth electrode may carry most of the diverted neutral current.

Where the PES is aware of such situations the customer should be advised to earth his radio equipment and any associated metal work to his own earth. This earthed metal work should be segregated from the earthing/bonding in the rest of the building and a Residual Current Device installed in the electrical supply to such equipment.

The same principles apply to radio stations within domestic premises.

3.2.19 Cell Phone Base Stations on 132, 275 or 400 kV Towers

Under earth fault conditions the Equipment Potential Rise of HV towers can be up to 50kV. Special precautions must be taken when providing LV supplies to these sites to prevent this potential being transferred onto the East Midlands Electricity network and causing danger to other customers. These sites shall be connected according to EA Engineering Recommendation G78. At the present time, Jan 2002, G78 is still in draft form. Obtain guidance from the East Midlands Electricity Equipment Specialist before committing to any connection work on these sites.

3.2.20 Caravans owned by the BBC or any Company within the Independent Broadcasting Authority

The blanket approval previously given for outside broadcast and similar caravans such as those owned by the BBC or IBA companies **is now withdrawn** and these caravans should not be offered a PME terminal. A Residual Current Device should be provided by the customer.

3.2.21 Multiple Services to Steel Framed Buildings

Where two or more services are to be installed into a single steel framed building:

- Only one service should make use of the PME terminal. (TN-C-S earth)
- The additional services should use an alternative earthing method such as TT earthing. These cut-outs should be labelled 'PME Not Available'.
- The service electrically nearest the substation must be at least 95 mm² CNE

Where a TT earthing is unacceptable to the Applicant he must be advised that multiple PME services in the building could cause the problems outlined in the attached Explanatory Note.

Several PME services may be provided subject to the Applicant agreeing to be responsible for resolving any problems caused by stray neutral currents.

Explanatory Note

Many modern commercial and industrial buildings are of steel frame construction. Where a single building is split in to two or more units there may be a separate service provided for each occupier. BS 7671 requires that the steel frame be bonded to the neutral/earth at the cut-out of each PME service.

The result of this practice is that a large proportion of the neutral current from services remote from the substation travels through the building's steel frame to the service nearest the substation. This results in two affects:

- Possible overloading of the neutral conductors of the nearest service
- Stray neutral currents causing high levels of EMF within the building causing computer VDUs to flicker and other equipment malfunctions.

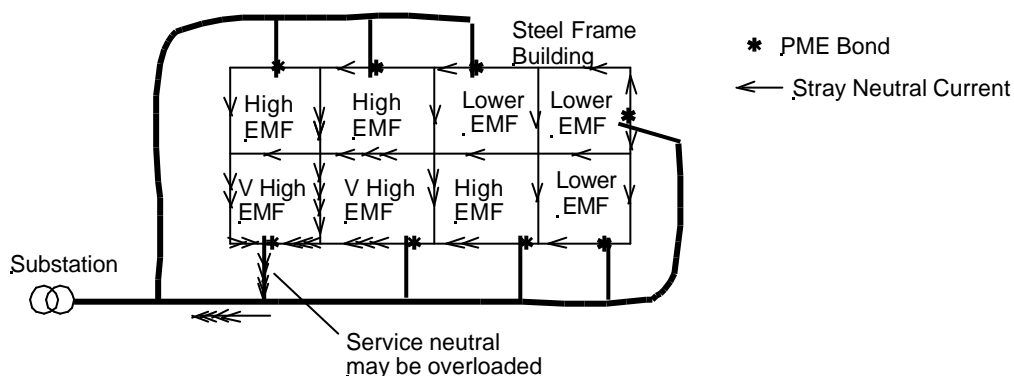


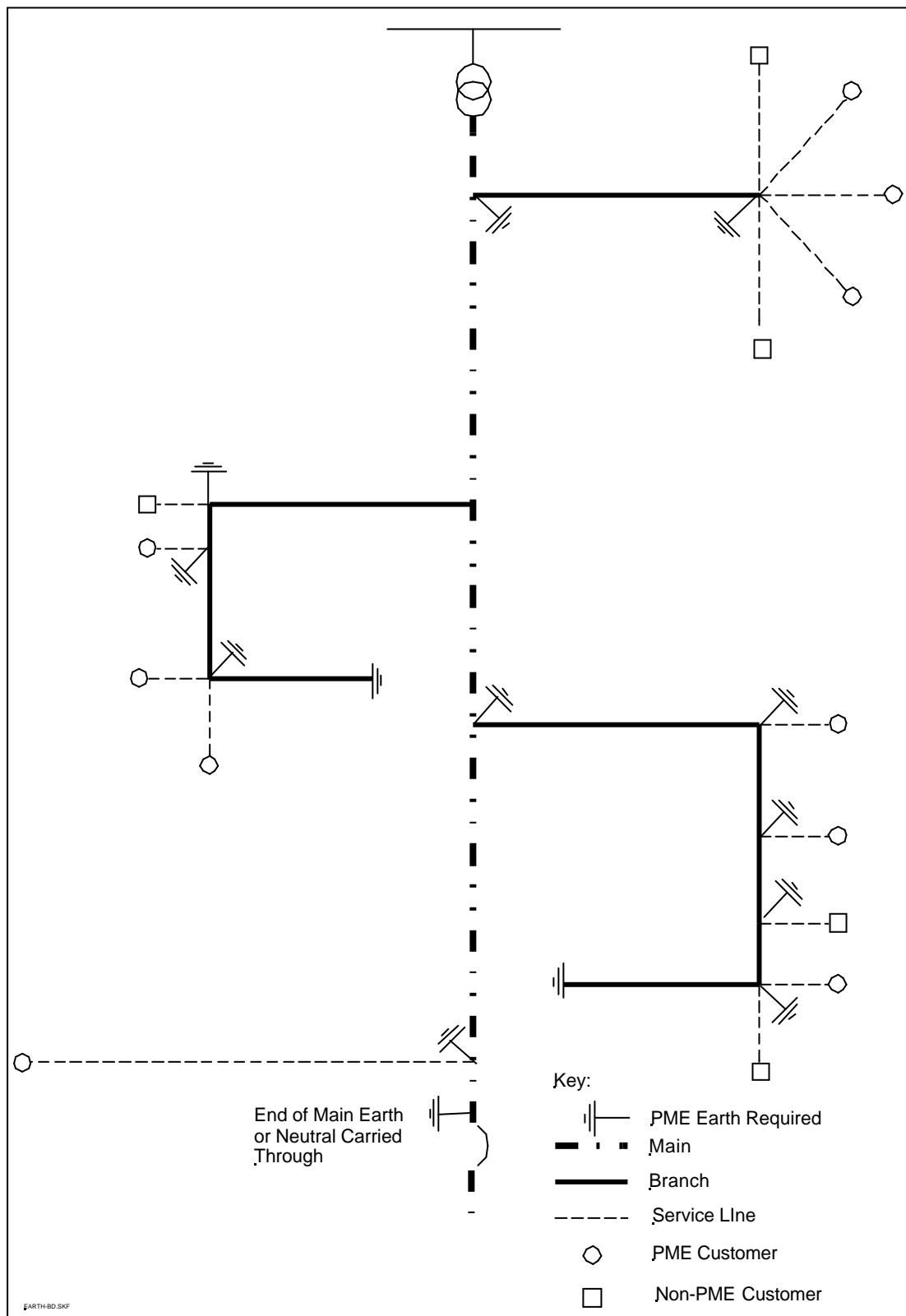


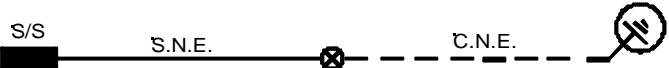
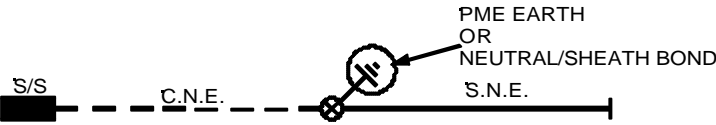
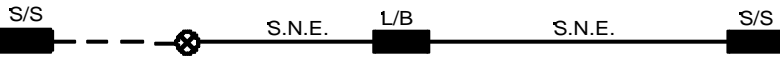
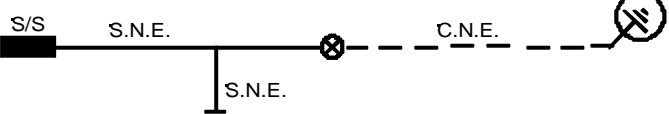
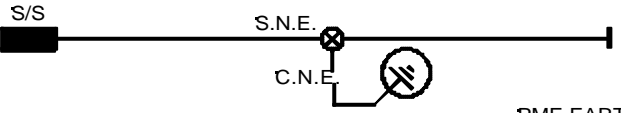
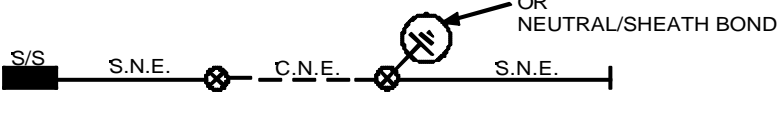
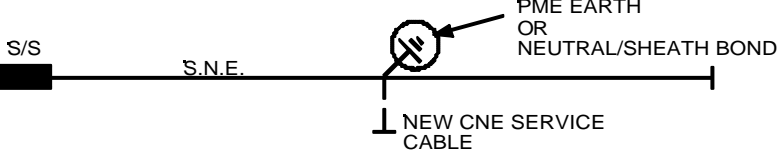
FIG.1. PME Earth Electrode Requirements

FIG.2. Typical Applications of CNE Cables

EXAMPLES	P.M.E. FACILITIES AVAILABLE
<p>TERMINOLOGY :- S/S = SUBSTATION</p> <p>L/B = LINK DISCONNECTING BOX (PHASE NORMALLY OPEN, NEUTRAL SOLID)</p> <p>C.N.E. = COMBINED NEUTRAL AND EARTH CABLE</p> <p>S.N.E. = SEPARATE NEUTRAL AND EARTH CABLE</p> <p> = P.M.E. EARTH</p> <p> = BOND BETWEEN SHEATH OF S.N.E. CABLE AND NEUTRAL OF C.N.E. CABLE</p> <p>1. </p> <p>2. </p> <p>3. </p> <p>4. </p> <p>5. </p> <p>6. </p> <p>7. </p>	<p>ALONG WHOLE LENGTH OF DISTRIBUTOR</p> <p>ON C.N.E. SECTION ONLY</p> <p>ALONG WHOLE LENGTH OF DISTRIBUTORS FROM BOTH SUBSTATIONS</p> <p>ALONG WHOLE ROUTE OF MAIN DISTRIBUTOR BUT NOT BRANCH</p> <p>ON C.N.E. BRANCH AND MAIN DISTRIBUTOR BETWEEN S/S AND C.N.E./S.N.E. JOINT</p> <p>BETWEEN S/S AND PME EARTH</p> <p>BETWEEN S/S AND SERVICE JOINT POSITION</p>

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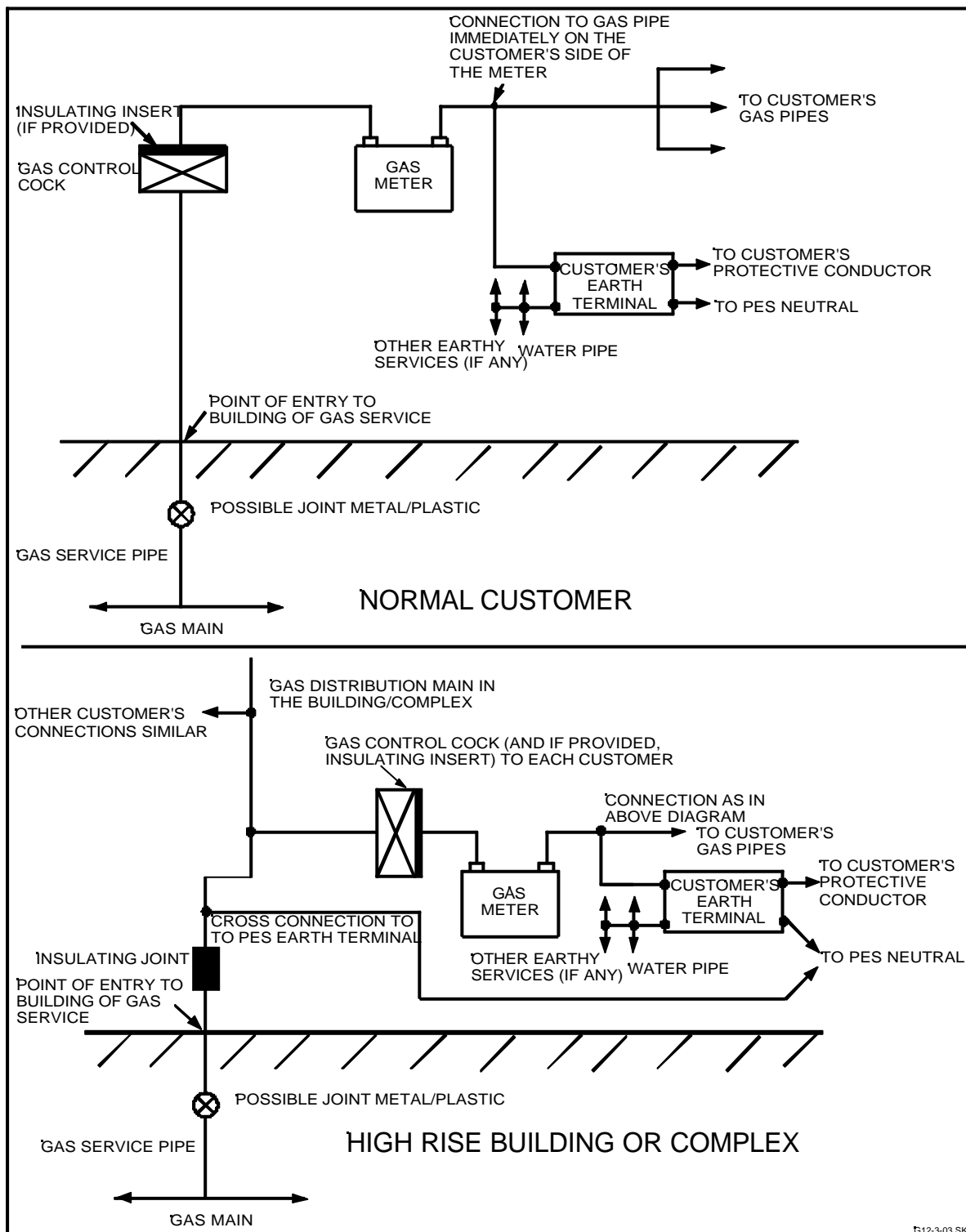
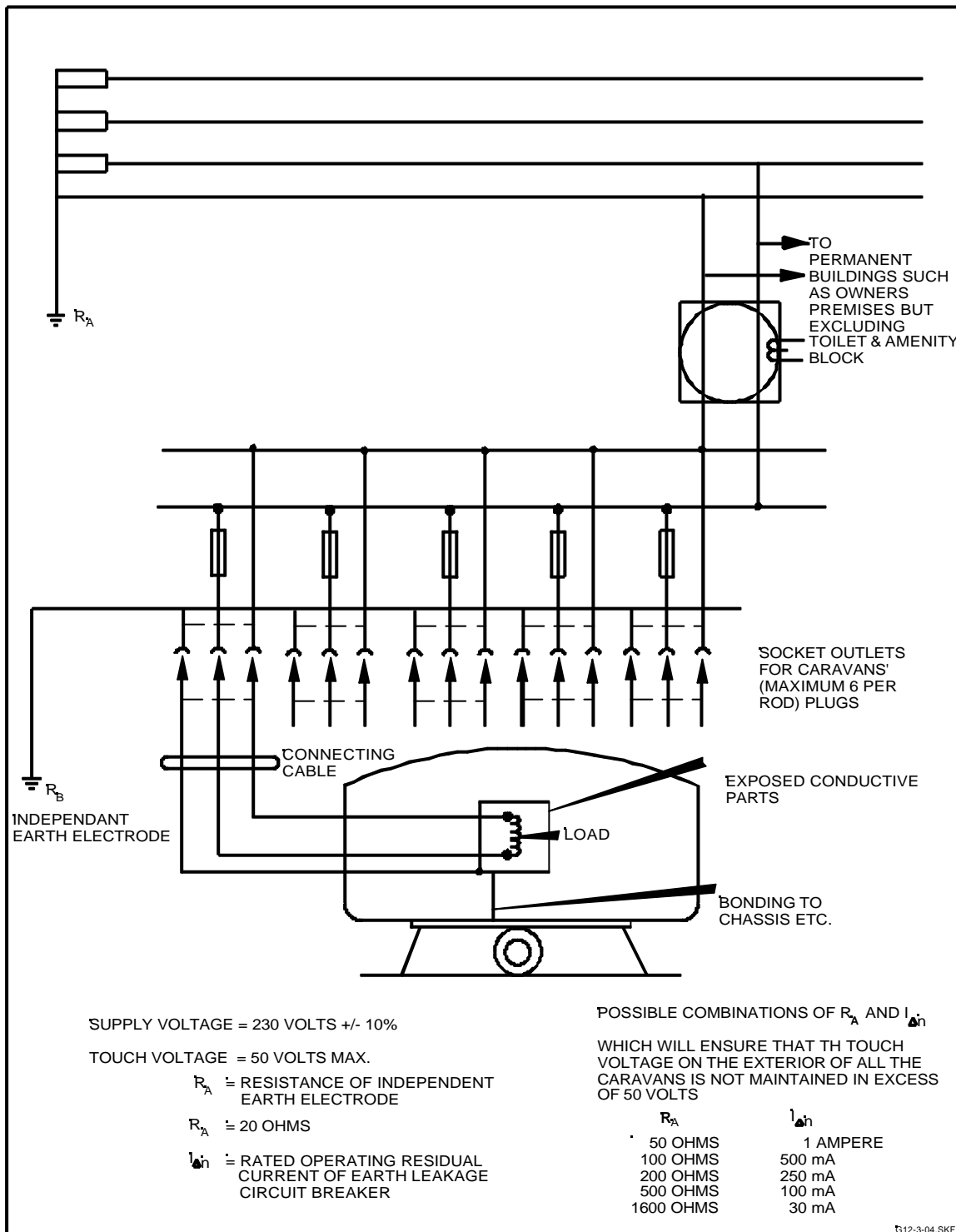
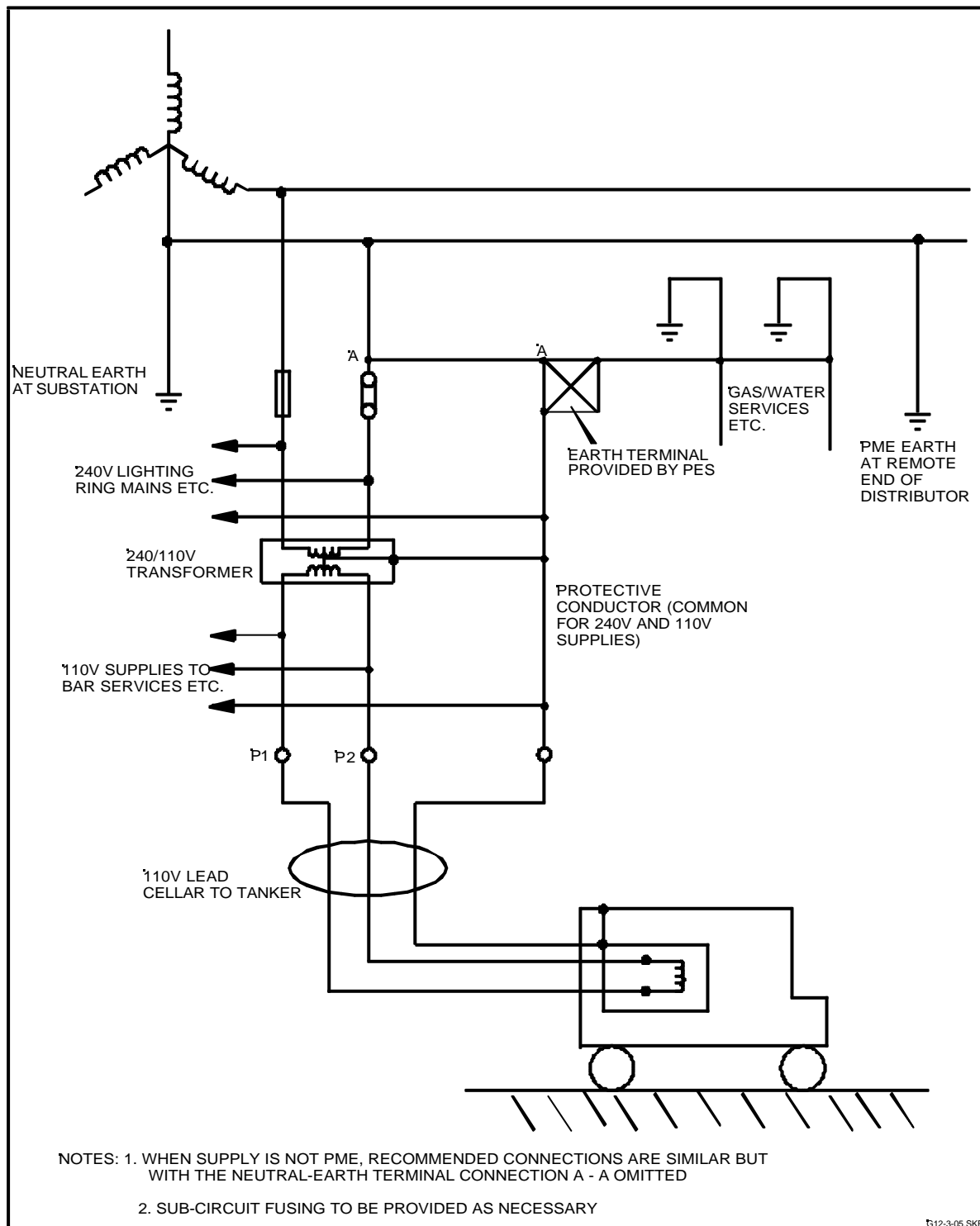
FIG.3. Method of Bonding Gas Service Pipes to Customer's Earth Terminal

FIG.4. Recommended Method of Supplying a Caravan Site



**FIG.5. Recommendations for the Connections of 240v and 110v Internal Distribution
When Supply is PME**

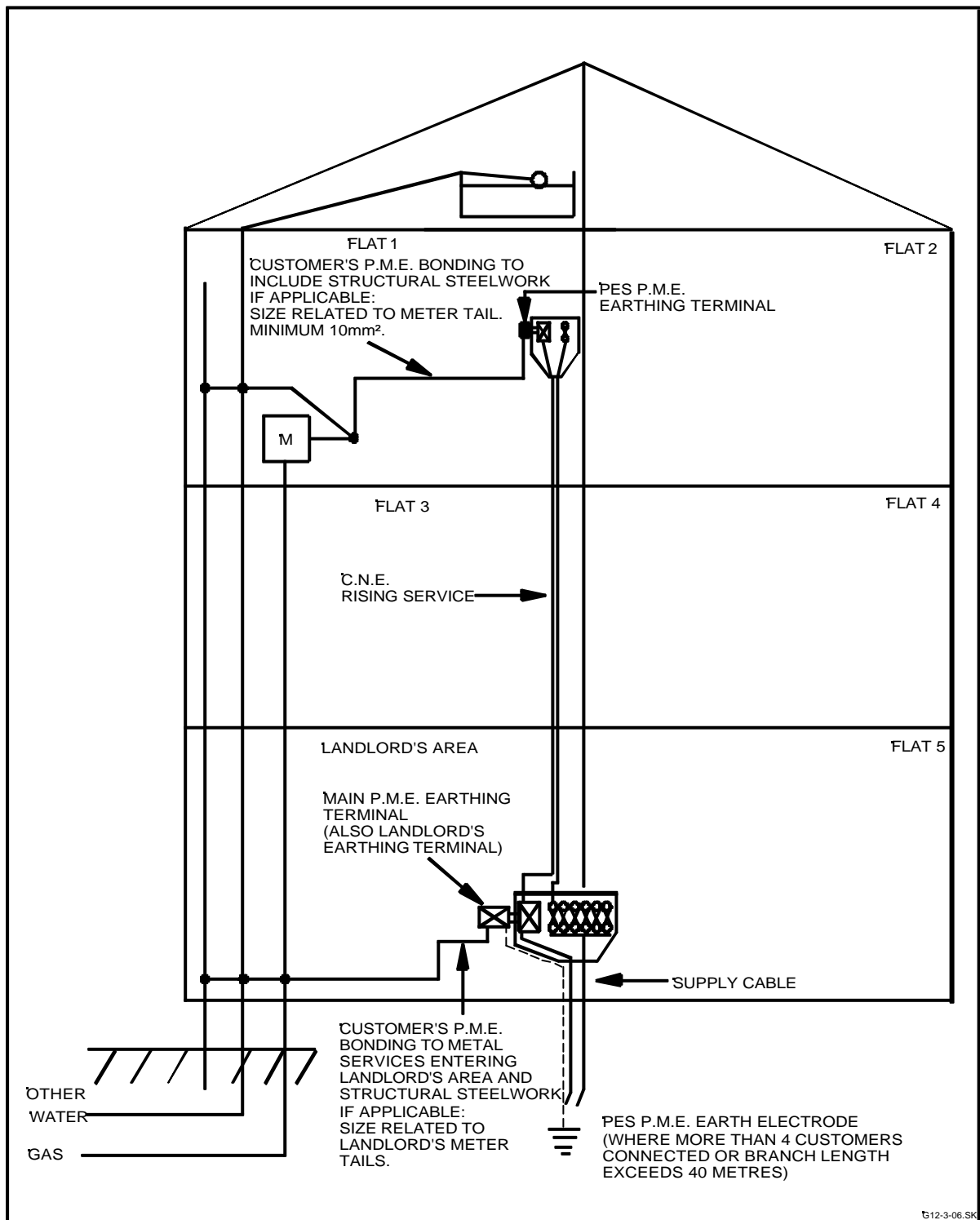
**FIG.6. New Multi-Occupied Building with CNE Rising Services: Meter Positions
Adjacent to Each Flat**

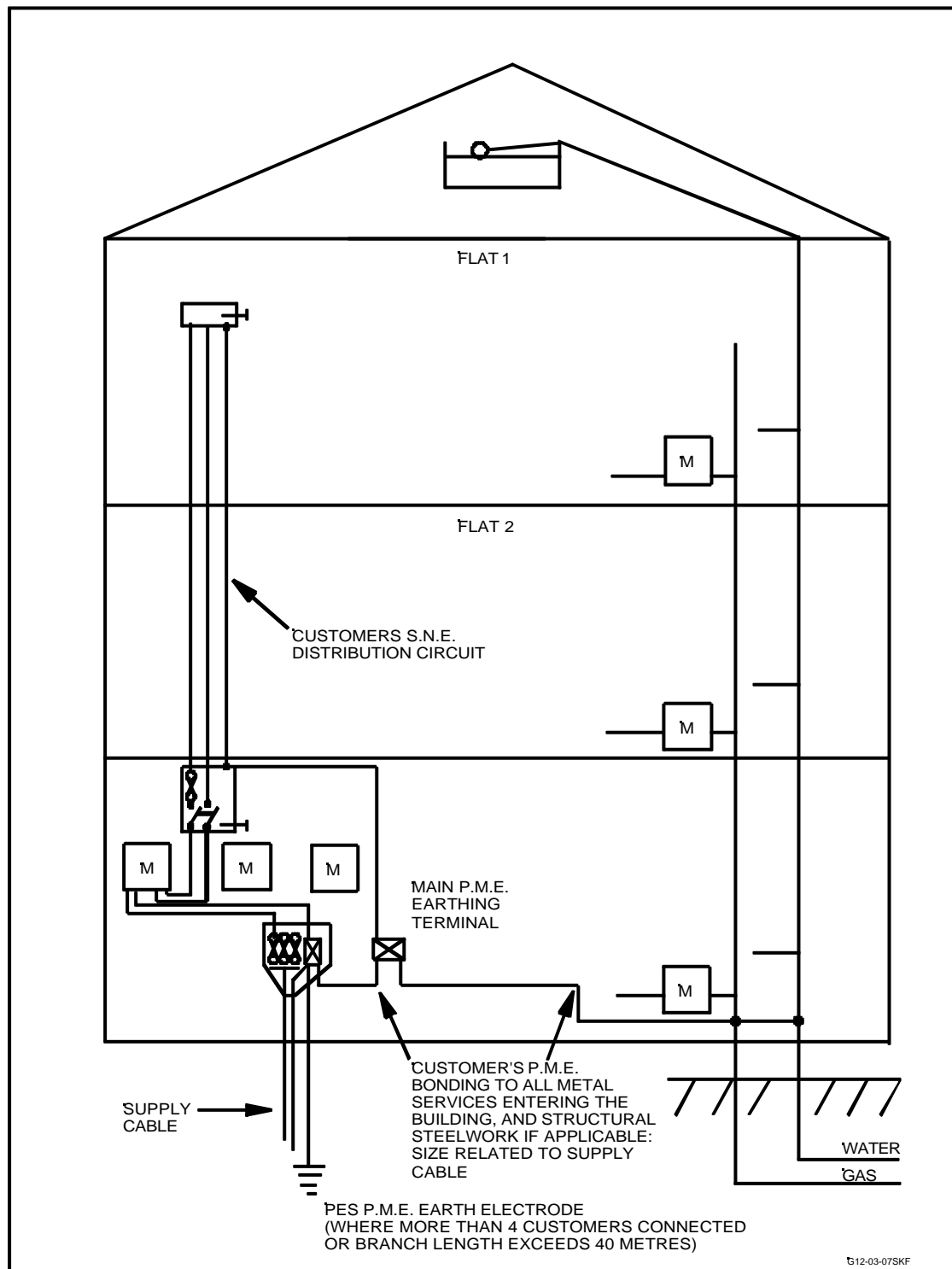
FIG.7. Multi-Occupied Building with Communal Meter Position

FIG.8. Multi-Occupied Building with Separate Neutral and Earth (SNE) Rising Services, Meter Positions Adjacent to Each Flat

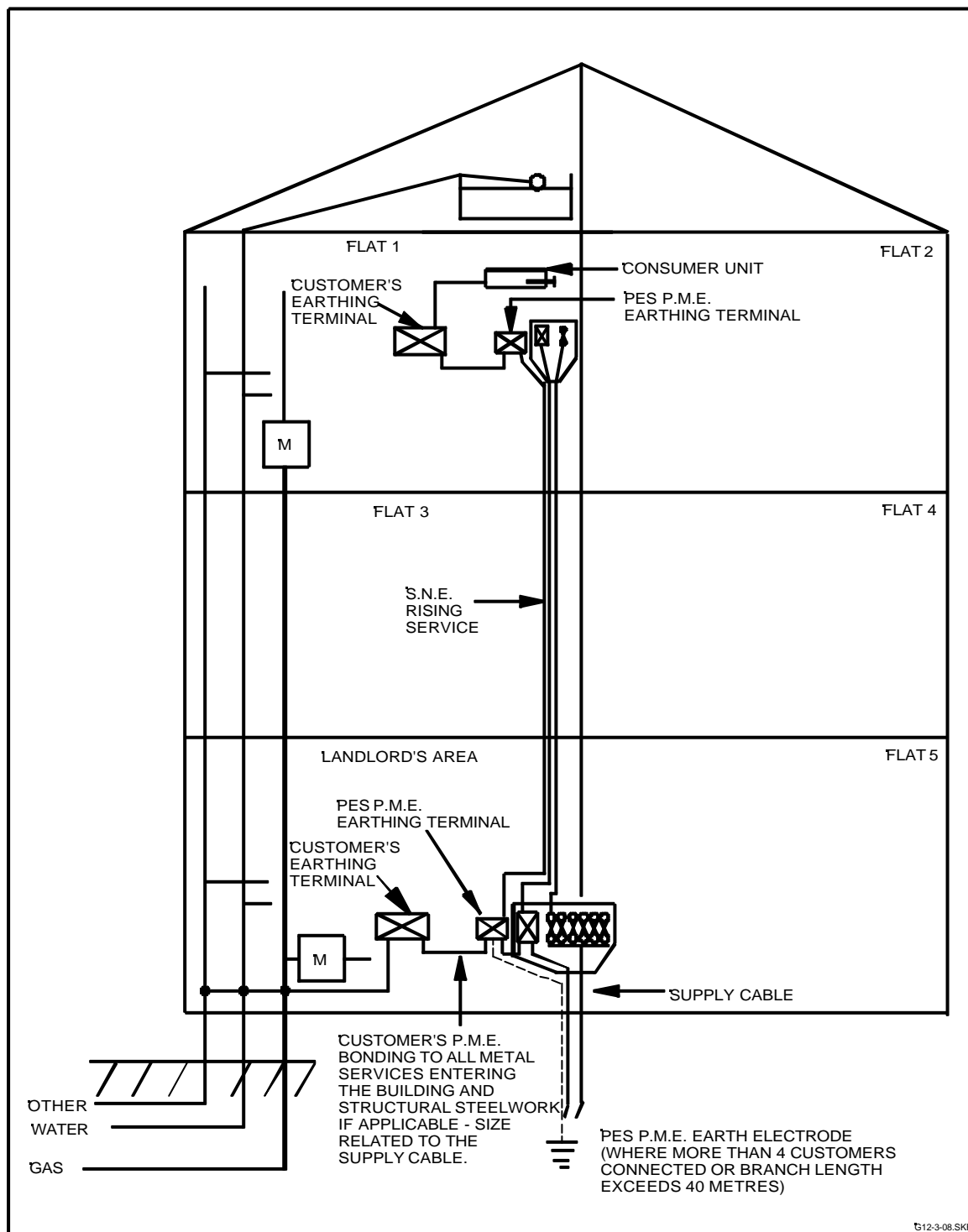


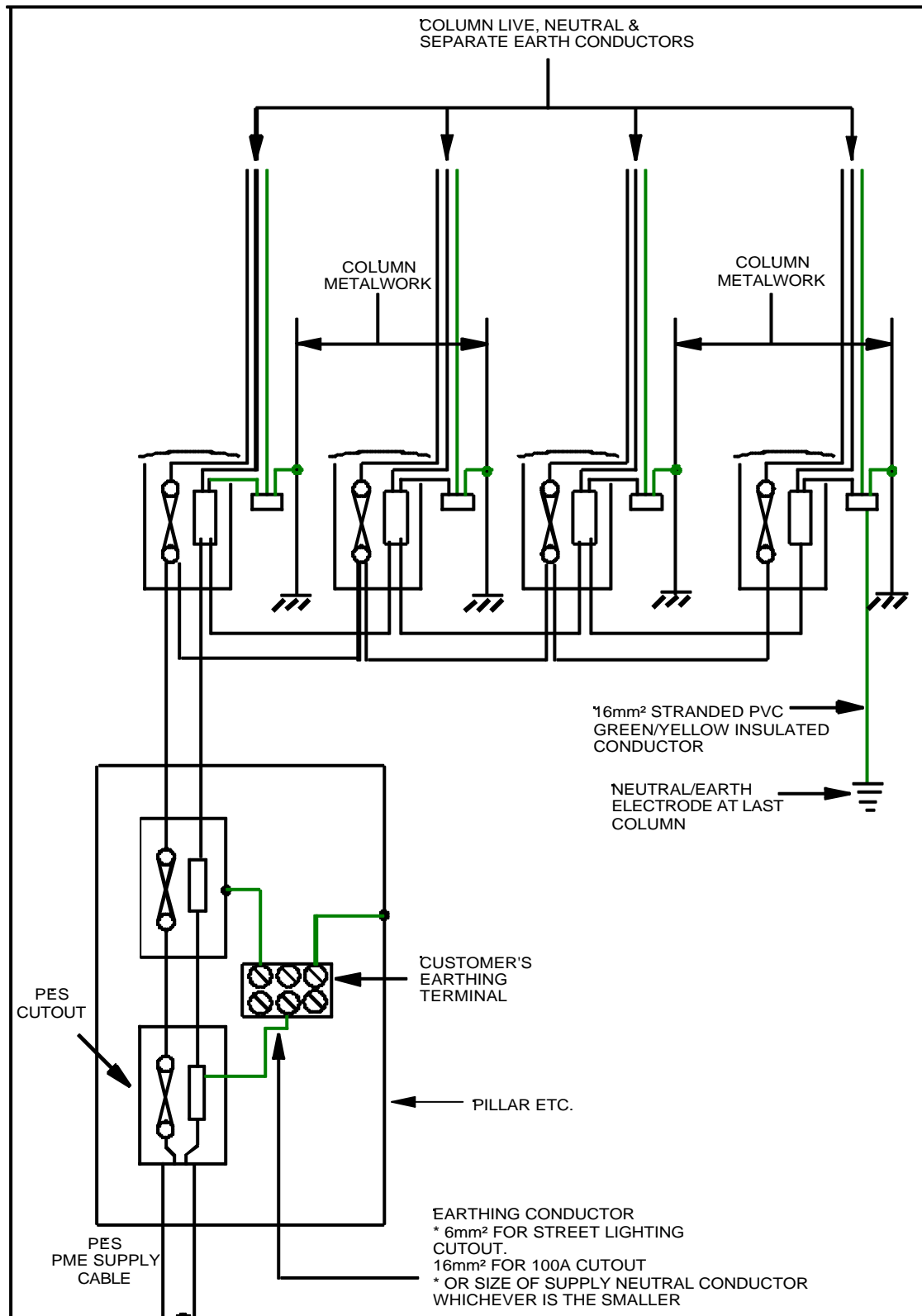
FIG.9. Lighting Authority CNE Distributor Fed From PME Service

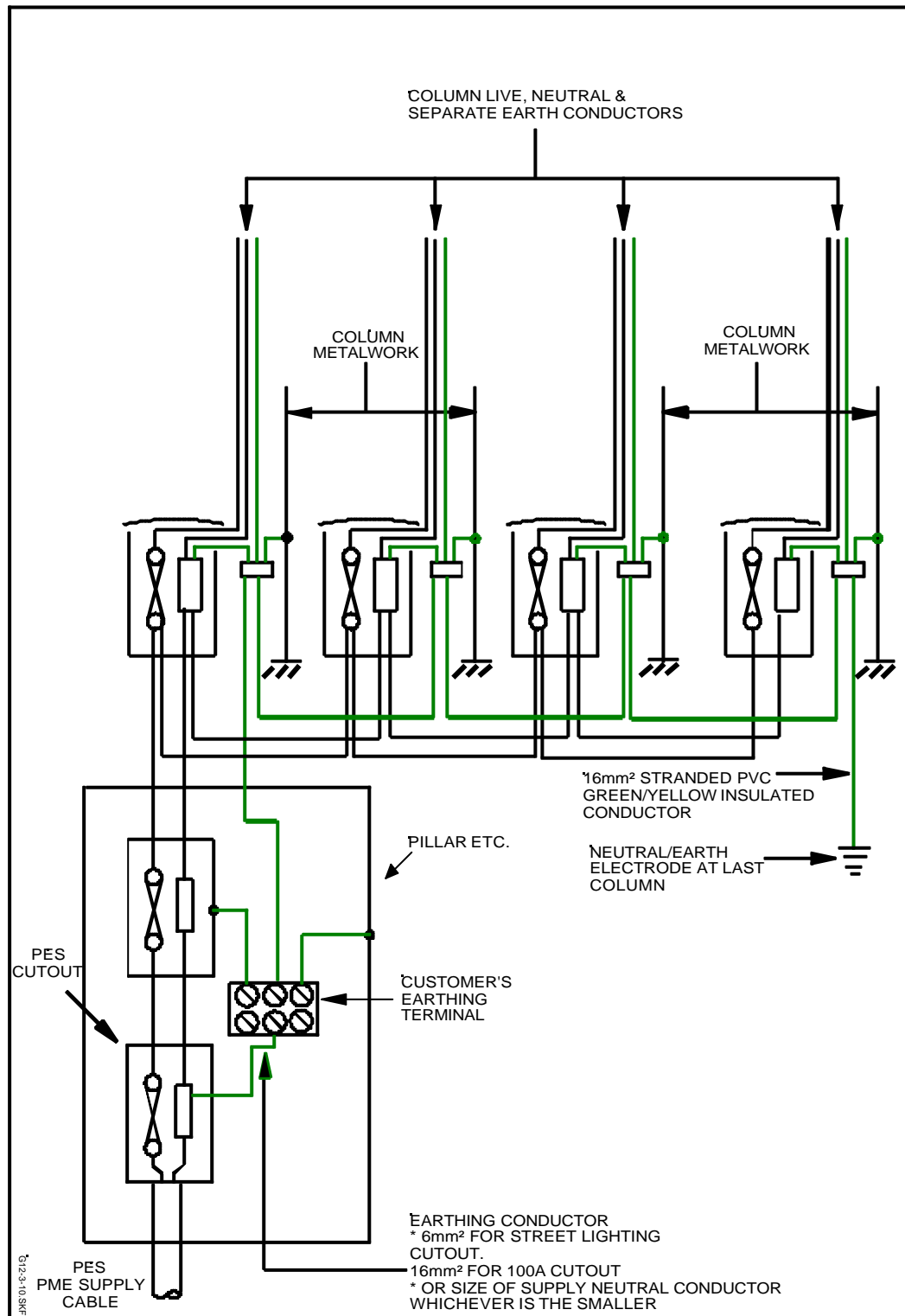
FIG.10. Lighting Authority SNE Distributor Fed From PME Service

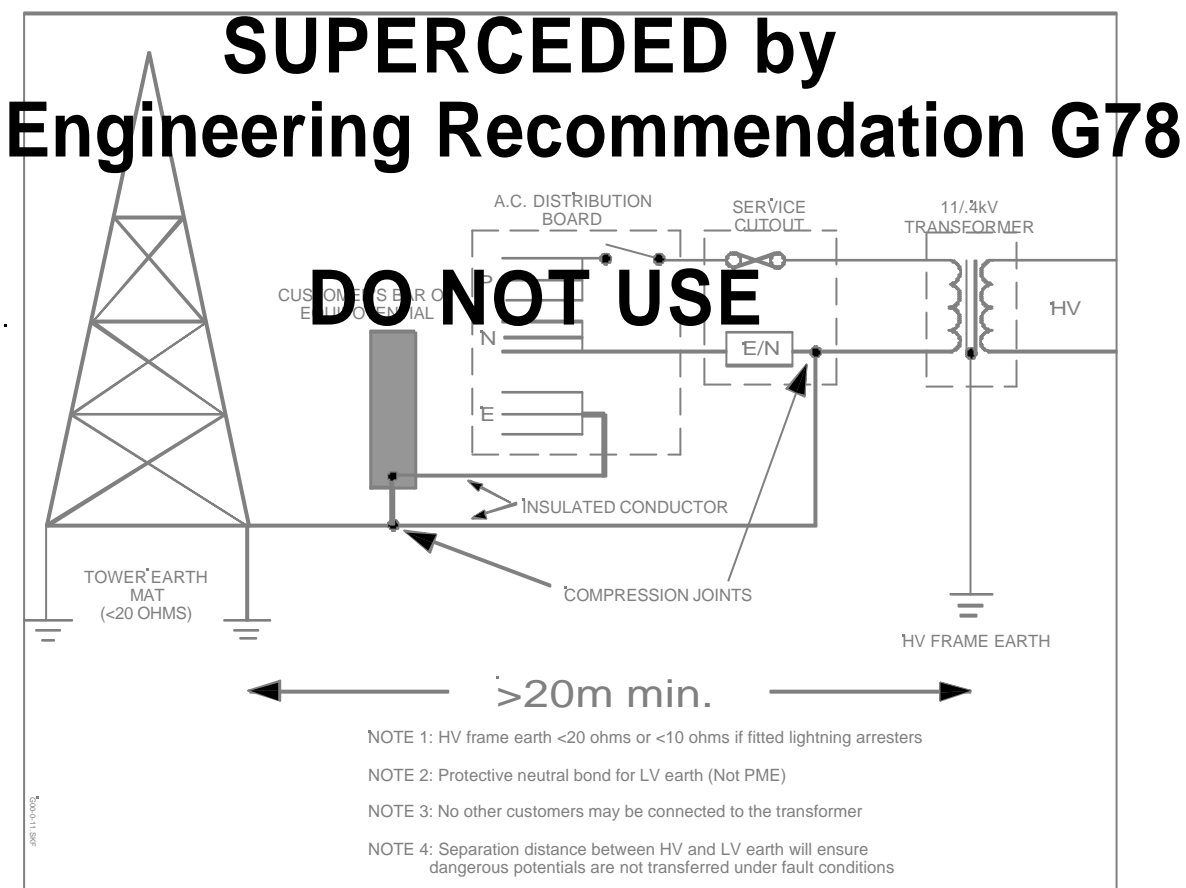
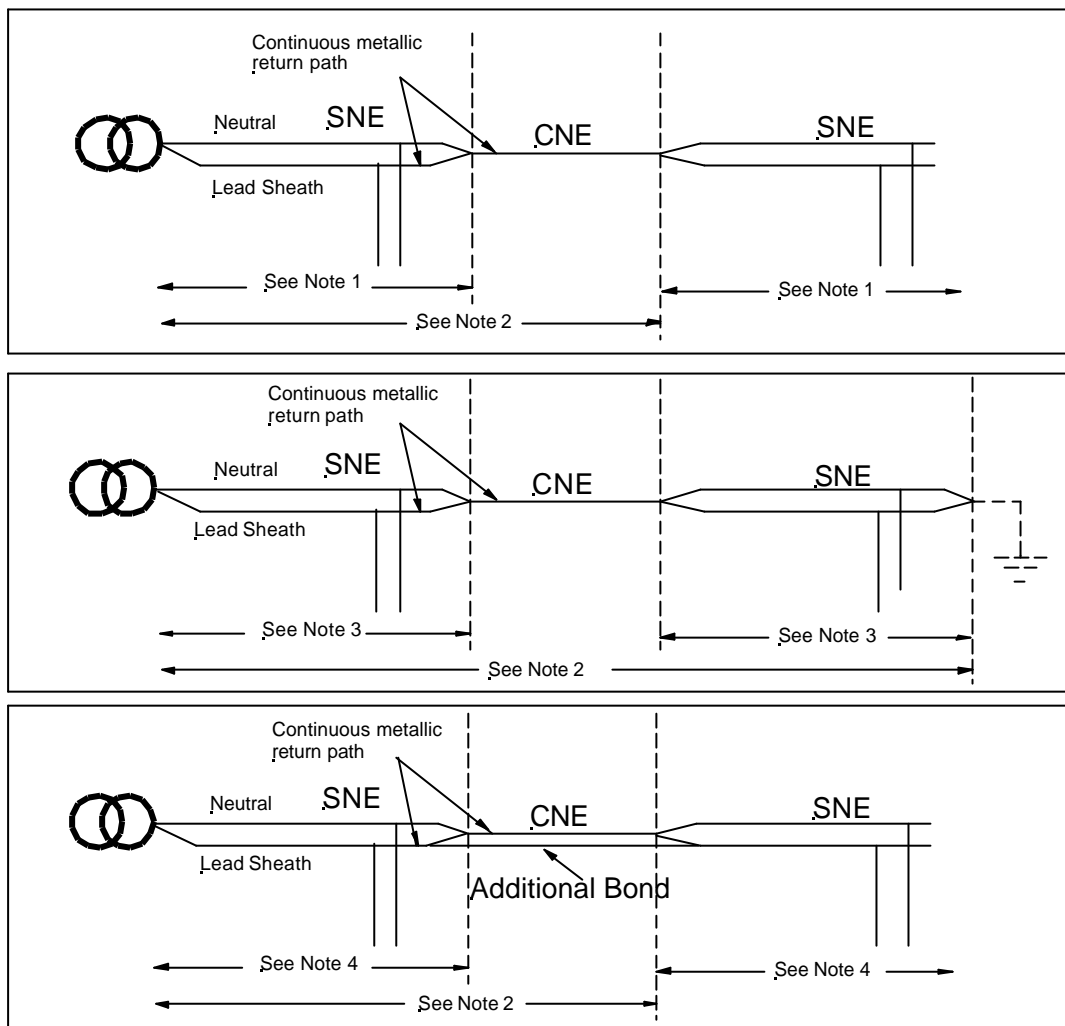
FIG.11. Supplies to Equipment Mounted on Electricity Towers and Communication Masts

FIG.12. Existing SNE Customer Installations**Note 1:**

This customer may retain an SNE earth provided that :
This section of SNE cable has a sheath to earth value of < 10 ohms. (See Table 3)

Note 2:

PME available up to this point provided customer installations meet bonding requirements of BS7671 : Electrical Installations of Buildings.

Note 3:

If the sheath earth value of this section of SNE exceeds 10 ohms the customer cannot retain an SNE earth. The following options are available:-

A. Earth fault protection can be provided by the customer fitting an RCD.

B. Convert SNE to PME. PME can then be made available subject to the customer's bonding meeting the requirements of BS7671 : Electrical Installations of Buildings

Note 4:

Customers may retain their SNE earth provided an additional bond connects the two SNE sheaths.

Section E7

Earth Specification

Overhead Network

Database Ref: 56	File Ref: E7 Earth Specification Overhead Jan 2002.doc	Manual Name: Earthing Manual
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Version	Prepared by	Approved by	Issue Date
2	Tony Haggis	Tony Haggis	Jan 2002

Revision Log For Section E7 Earth Specification Overhead Network

Changes made in version 1	
Section	Notes about the change
E7	First Issue

Changes made in version 2	
Section	Notes about the change
Section 7.1.8	Separate earthing of 33kV XLPE cable support channels
Section 7.2.2	Guidance on transferred potential with regard to metal fences clarified.

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1. GENERAL

This specification applies to overhead lines up to 33kV on wood poles and steel towers.

The earth installation design will provide for the following functions:

- (a) Provide a low impedance path to enable fault current at any point on the electrical network to be returned to the transformer or generator neutral(s), without thermal or mechanical damage to connected apparatus, and to enable protective equipment to operate correctly.
- (b) Limit voltage rises, on all metalwork and the surface of the ground to which persons have normal access, to a safe value under all reasonably perceived conditions. The earthing system will be so constructed as to prevent the establishment of dangerous potential differences between parts of the installation, which a person may be contacting simultaneously.

2. TECHNICAL SPECIFICATION

Your earth electrode design will comply with:

The Powergen Engineering Minimum Standard “The Design, Application, Testing and Maintenance of Earthing Systems”

and

East Midlands Electricity Local Management Instruction for Distribution System Earthing.

3. EARTH POTENTIAL RISE

You will assume for this type of installation that the EPR is **above 430v** and the installation will be classified as ‘hot’.

4. EARTH ELECTRODE VALUE – WOOD POLE

Where poles support earthed plant the maximum electrode resistance value will be:

- 20 Ω on installations without lightning arresters
- 10 Ω for installations fitted with lightning arresters.

5. EARTH ELECTRODE VALUE – TOWER

The maximum earth electrode value will be 6Ω for tower footing resistance.

6. RECORDS

You will measure and record soil resistivity and electrode resistance for inclusion in the Asset Data Base.

7. WOOD POLE LINES

7.1 Wood Pole Steelwork – General .

Overhead lines shall normally be of unearthed construction. All pilot pins are to be bonded together and to the line crossarm. Poles supporting plant shall normally have all steelwork bonded together and be earthed except where stated otherwise below.

Refer to Section “E5 Distribution Standard Earthing Layouts” for the recommended installation details.

7.1.1 Live Line Rod Operated Switches or Fuses

- The steelwork of Expulsion Fuses and Air Break Switch Disconnectors with high level actuation **shall not be earthed**.
- The plant steelwork shall be bonded to the crossarm using a live line operable earth clamp. This bond is to be temporarily removed whilst carrying out maintenance or repairs to the switchgear with the lines alive.

7.1.2 Hand Operated Pole-Mounted Switchgear.

- Air Break Switch Disconnectors (ABSD) with low level actuation **shall be bonded to the crossarm and earthed**.
- The bottom section of the operating rod shall be fitted with an insulated insert at least 3 metres above ground.
- The operating handle **shall not be bonded** to the main HV earth
- An earth mat shall be installed under the place where the operator stands. This mat shall be connected to the operating handle.

- The HV earth electrode shall be installed on the opposite side of the pole to the operating handle at least 5 metres or 1.5 x the earth rod depth (whichever is the greater) from the pole.
- The HV earth electrode shall be connected to the ABSD steelwork with insulated conductor to maintain electrical segregation between the HV earth and the operator's earth mat and handle.
- Approved rubber gloves are to be worn during switching operations to provide a further level of protection

7.1.3 Tee-off Poles

- Tee-off crossarms **shall not be bonded** to the main line crossarm.

7.1.4 Transformer poles

- The transformer tank shall be directly earthed with a continuous conductor using the deep earth technique. The HV earth conductor shall be kept as straight as possible, right angle bends are not permitted as they present a high impedance to lightning pulses.
- All steelwork **shall be bonded** to the transformer deep earth conductor.
- The HV and LV earths electrodes shall be segregated
- The HV earth conductor shall be insulated to at least 3 metres above ground level.

7.1.5 Non Automated Pole Mounted Auto Reclosers

- Non-remote control auto reclosers (i.e. Live Line rod operated) **shall be bonded** to the crossarm but **not earthed**.
- The plant steelwork shall be bonded to the crossarm using a live line operable earth clamp. This bond is to be temporarily removed whilst carrying out maintenance or repairs to the switchgear with the lines alive.

7.1.6 Automated Pole Mounted Auto Reclosers

- Automated control auto reclosers **shall be earthed**.
- All steelwork, including the dedicated supply transformer, control box and control cable screens shall be bonded to the main HV earth.

- An earth mat shall be installed under the place where the operator stands. This mat shall be connected directly to the control box. The control box **shall be bonded** to the main HV earth.
- An Earth Electrode Perimeter Conductor shall be installed around the pole at a 2 metre radius to provide an equipotential zone.
- The LV neutral of the dedicated supply transformer **shall be** connected to the HV earth.
- This transformer **shall not** be used for supplying other customers.
- The Auto Recloser **shall not** have its LV supply derived from a local LV network supplying other customers.

7.1.7 Stays on HV Poles.

- The pole top make-off of all stays are to be bonded to the line supporting steelwork, using the integral 'king-wire' of the helical make-off.
- The 1970 Overhead Line Regulations require that each stay on an HV pole has an insulator fitted to prevent the bottom of the stay becoming alive during earth faults.

7.1.8 HV Cable Terminations.

- The cable sheath and armour must be bonded to the mounting steelwork associated with the termination. The connection between cable and steelwork is to be kept as short as possible.
- The HV earth conductor shall be insulated to at least 3 metres above ground level.
- The lower cable support channels (within 3m of ground level) of 33kV XPLE cable terminations **shall be earthed separately** from the main steelwork earth.

7.1.9 H-poles are fitted with cross-bracing gear

- Care is to be taken that the lowest component of this cannot become 'alive'.
- Un-earthed construction:
 - If any part of the cross-brace is **less than 3 metres** above ground **it must be earthed** to an earth rod. It **shall not be bonded** to the pole top steelwork
 - If the lowest member is **more than 3 metres** above ground it **must not be earthed**. It **shall be bonded** to the pole top steelwork.

- Earthed construction:
 - If the line is of earthed construction the cross bracing **shall be earthed and bonded** to the pole top steelwork.

7.1.10 LV Steelwork and Equipment.

- Pole mounted equipment such as the metallic tanks of regulators, static balancers and metallic cable **boxes shall be bonded** to the neutral conductor.
- Pole bolts associated with reel insulators or 'D'-irons and eye bolts and hook bolts with keeper plates on LV wood poles **do not require bonding** together.
- Pole-top stays make-offs **do not require bonding** to pole top steelwork.

7.2 Precautions Against Step and Transfer Potentials

7.2.1 Step potentials

Under fault conditions a voltage gradient is created around the electrode for the duration of the fault. Persons in outdoor footwear will not normally be affected. However, Livestock or barefooted persons are particularly susceptible to such voltages, which can result in discomfort or injury. Therefore, avoid running earth electrodes across gateways, field entrances, bridle paths or children's play areas.

7.2.2 Transferred Potentials

Under fault conditions a voltage gradient is created around the electrode for the duration of the fault.

The earthed connections of pole mounted plant must be insulated within 3m of ground level to prevent persons making contact between HV earths and the ground or remotely earthed metalwork such as wire fences.

Where metal fencing is supported on metal posts the HV earth electrode voltage can transfer through the ground onto metal fencing and then be exported along the fence. Therefore, avoid running earth electrodes close to metal fences posts. Ideally you should maintain the same separation as you would between HV and LV earths. Where this is not reasonably practicable you must maintain at least 3m separation subject to a risk assessment to establish that any voltage transferred will not result in an unacceptable hazard.

8. TOWER LINES

Earthing of these metallic supports is required both to provide paths for the discharge of power-frequency currents and also high-frequency discharges experienced under lightning conditions. The requirements are as follows :-

- (a) When steel supports are accompanied by an over-running earth-wire the earth-wire shall be bonded direct to the tower or support. The connection shall be made using an approved non-tension joint to a jumper bolted to the support metalwork. This ensures that an adequate electrical connection exists, rather than a fortuitous one via the support saddle and fittings.
- (b) In the case of towers, the foundation legs provide an adequate earth electrode and additional earthing is not normally required. The exception would be in very high resistivity ground where additional earth electrode will have to be installed.
- * In all cases, the resistance of each footing is to be measured prior to connection of the earth-wire, to ensure the value is less than that shown above.
- (c) For other metal supports or masts, every effort should be made to make full use of the foundation steelwork by using a formal bond to the steel reinforcing bars at the base of the foundation where the steelwork does not adequately provide this.
- (d) Whilst the standards, at present, do not require grading electrodes, there are situations where it is prudent to provide potential grading electrodes, situated approximately 1m beyond exposed metal work and at a depth of 1m. These include:
 - Terminal towers/structures (where grading is not provided by the main earth grids).
 - Transition structures (overhead line to underground cables).
 - Surge diverter locations.
 - Locations where the public has regular access, particularly if normal footwear is often not used (e.g. near footpath to beach, caravan sites etc.).

9. MATERIALS

The following materials are to be used in the construction of the earth installation.

TABLE 1. ELECTRODE AND BONDING MATERIALS

CONDUCTOR TYPES	SIZE mm ²	COLOUR	TYPE
-----------------	-------------------------	--------	------

Main earth using copper bonded rods	50	Black	Hard drawn, PVC sheathed and un-insulated, copper
Main earth using deep earth system	50	Black	Hard drawn, PVC, sheathed/ un-insulated copper
Earth bonds and mats	50	Bare	Hard drawn, un-insulated, copper

Note 1: All earthing conductors are to be insulated to a minimum of 3m above ground level. Earthing conductors do not have to be un-insulated above 3m. It is acceptable and preferable to use insulated conductor for all above ground earthing connections on pole installations.

Note 2: All underground conductors that connect individual electrodes together are to have the insulation removed, except where insulation is required to maintain HV and earth mat separation distances.

10. APPROVED CONNECTIONS

TABLE 2. APPROVED METHODS OF CONNECTION

Connection Type	Compression Lug	Phosphor Bronze Clamp	Copper 'C' Crimp	Exothermic Weld
Main earth conductor to rods	✗	✓	✗	✓
All earth bonds to main earth conductor	✗	✗	✓	✓
Main earth conductor to main earth conductor	✗	✗	✓	✓
All connection to steelwork and equipment	✓	✗	✗	✗

Note 1: The stay is to be earthed by terminating one strand of staywire or the bonding wire of the pole top make-off to an assembly bolt on the crossarm.

Note 2: Under no circumstances are earth terminations to be made between the wooden pole and the steelwork, as pole shrinkage results in loose connections.

Note 3: Where it is practical exothermic weld connections are to be used in preference to the other types of approved connectors, as they give a better electrical connection. Follow the supplier's instructions for correct and safe use of the exothermic weld.

Section E8

132/33/11kV & 33/11kV

Earth Grid Design

Guidance Notes

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Version	Prepared by	Approved by	Issue Date
1	Tony Haggis	See Database	02/2001

Revision Log For Section E8 132/33/11kV & 33/11kV Earth Grid Design Guidance Notes

Changes made in version 1	
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1. INTRODUCTION

These guidance notes are intended to guide you through the process of designing an effective earth system for a 132/33/11kV or 33/11kV substation installation in accordance with EME policy, which is itself aligned with national and industry standards. The process is set out below in the form of a flow chart. The steps of the flow chart are supported by accompanying notes in the sections that follow.

Note. RESAP and MALT are sub packages of CDEGSTM earthing analysis software which is the package currently approved by East Midland Electricity.

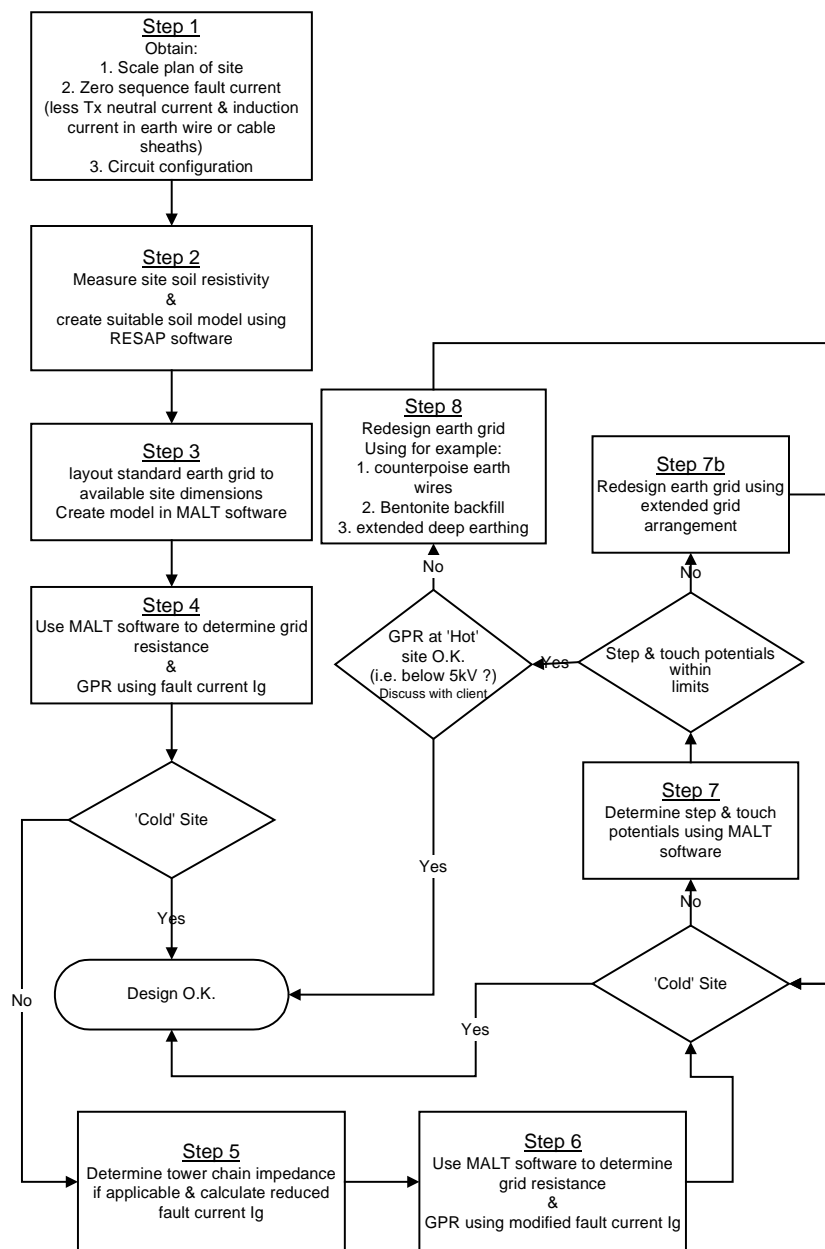


FIG.1. EARTH DESIGN PROCESS

2. REQUIREMENTS OF THE FINALISED DESIGN.

The finalised design will provide the following:-

- a) The Grid Resistance and Overall Earth Return Impedance values.
- b) The earth potential rise (EPR), for a maximum value of ground current.
- c) Specify whether the substation is hot or “cold”.
- d) Show the limits of the hot zone - if applicable.
- e) Confirm that at all points, the internal maximum touch and step potentials are below the safe acceptable value.
- f) Confirm that at the fence, the maximum touch potentials are below the safe acceptable value.
- g) Confirm that the maximum external step potentials are below the safe acceptable value.
- h) Where the design makes significant use of vertical rods, the fault current distribution within the grid is required to ensure that copper clad steel rods can carry their proportion of current without damage.
- i) Ensure that there is earth electrode reasonably close to each item of plant which requires connection to it.

3. INITIAL DESIGN REQUIREMENTS (FIG.1. - STEP 1)

The following information is required to enable a substation earth system to be designed:-

1. Scale plan of site.

This will be used to plot the physical layout of the earth design, and to obtain site dimensions for the design calculations. A copy or copies will be provided with the design specification.
2. Worst case zero sequence fault current (I_e).

The fault current will be used to calculate the Earth Potential Rise. This information will be provided in the design specification.
3. Circuit configuration and electrical characteristics.

This will enable the calculation of any parallel earth paths, such as chain impedance.

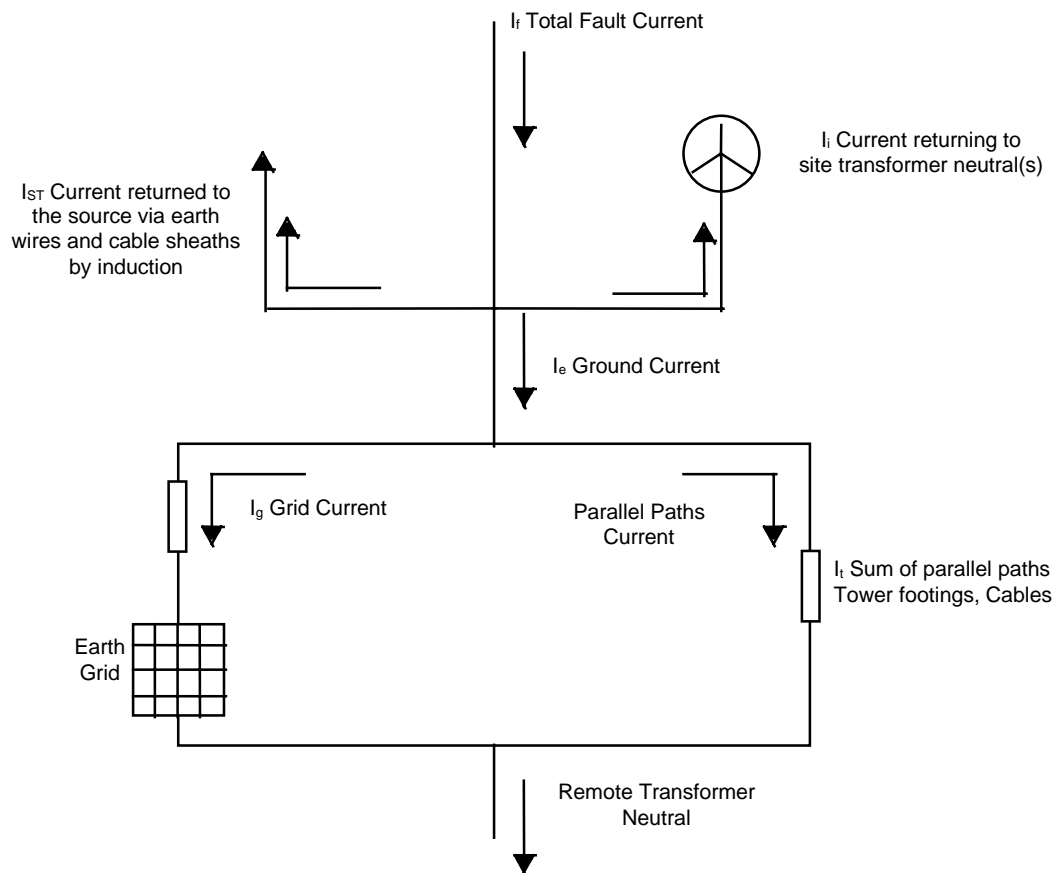


FIG.2. EARTH FAULT CURRENT PATHS TO CONSIDER

3.1 Data Required from the Power System Fault Study.

The objective is to determine the total earth fault current which is available to flow into a substation earth impedance (which includes the earth grid plus its parallel paths). The network should be modelled using fault levels anticipated for a reasonable period into the future (say five years) to obtain the maximum single phase to earth fault available due to either an internal or external fault condition at the substation. The internal fault is a primary high-voltage bushing or bus bar failure to earth at the highest voltage level in the substation, or a fault thrower operation. The external fault condition normally involves an earth fault on a lower voltage outgoing circuit, particularly one supplied by unearthed overhead line, as more current will return through the ground.

Internal fault conditions within the substation at lower voltages do not normally require investigation, as most of the current should return via the installed electrode system back to the star point. This will not create a significant rise of earth potential, unless the earth grid has been incorrectly designed. In this case, significant potential differences may occur across the substation.

A distinction must be made between 132kV networks and 33kV networks. It is normal practice for 132kV networks to be multiple earthed i.e. at sending and receiving ends, whereas other networks are normally earthed at one point. For 132kV faults, this means that a portion of the fault current will return to source via phase conductors. In order to estimate the current returning in this way, the individual phase current in each transformer winding during the fault is required and these need to be summated vectorially to find the residual. This would be subtracted from the gross earth fault current in the calculation of the EPR. Note that this includes the current flow in earthing transformers. For 33kV networks, it is normal practice to provide a connection with earth at the sending end only, this means that all the earth fault current returns to the sending end.

3.2 Earth Fault Current Returning via Earthwire/Cable Sheaths due to Induction.

When a conductor lies parallel to another and an alternating current flows in one of them, then, provided a complete circuit is available on the second conductor, a current will be induced in this second circuit. This is experienced in practice in tower lines and underground cables. The metal tower line earthwire forms a complete circuit as it is earthed at each end, so current will be induced in it. Similarly, if the earth sheath of a single core cable is earthed at each end, current will be induced in this due to the unbalanced earth fault current flow in one core.

The current which is induced into the cable sheath or aerial earth wire returns to source(s) without flowing through the ground. This current will not therefore pass through the earth grid or its parallel paths and will not contribute to any rise in potential. In order to arrive at an accurate estimate of the rise of earth potential it is necessary to calculate the amount of current which returns through the ground. The components returning via metallic routes need to be subtracted from the figure provided by traditional earth fault level programmes, to provide this net value.

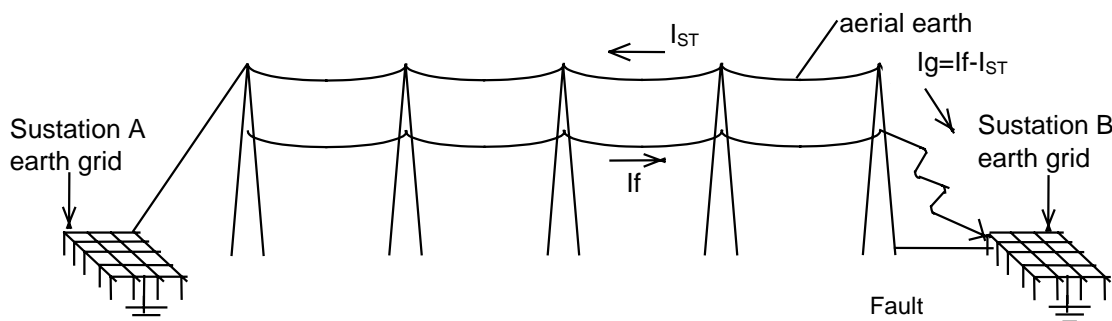


FIG.3. EARTH WIRE RETURN CURRENT VIA INDUCTION

I_f = Maximum earth fault current from fault study

I_{sr} = Current induced into earth loop, in effect opposite to I_f

$I_g = I_f - I_{sr}$

In a similar manner, I_g for a cable fault is reduced by the value I_{sr} , which would be the current returning through the cable sheath.

3.3 Overhead line with Earth Conductor.

To determine the value of ground current returning via conduction down the earthwire refer to Table 2 of Engineering Recommendation S.34. However, note that the earthwire must be continuous back to source. If a section of unearthed construction (e.g. Trident) is installed, then the table cannot be used.

3.4 Cables

To determine the proportion of ground current, Engineering Recommendation S.34 has a series of easy to read nomographs. These are summarised in Table 1 below.

TABLE 1. CALCULATION OF GROUND CURRENT FOR CABLE FAULTS.

S.34	Fault on Cable section			
Figure No	kV	Size(s)	Type	Supply Source
8	33	Standard	P.I.L.C.	All cable
14	132	630mm ²	P.I.L.C.	All cable
13	33	Standard	P.I.L.C.	Via O.H.
16	132	630mm ²	3 x 1 P.I.L.C.	Via O.H.
17	132	630mm ²	3 x 1 PICAS	Via O.H.
10	33	Standard	P.I.L.C.	Cable
15	132	630mm ²	P.I.L.C. or PICAS	Cable

To use the nomographs, it is necessary to know the length of cable, the cable type, the earth impedance at each end and the method of connection. Normally it is necessary to divide the sum of the two end impedances by the cable length (in metres). This factor, when used with the nomographs, enables the percentage of fault current returning through the ground, together with its phase angle, to be selected from the figures for each particular type of cable.

4. SOIL RESISTIVITY MEASUREMENTS (FIG.1. - STEP 2)

Prior to designing the earth grid a soil resistivity test needs to be carried out. This will enable the resistance of any design to be determined. It will also give an early indication as to if the site will be hot, how extensive the design work will be, and whether advantage can be taken from underlying low resistivity soil layers.

Soil resistivity and corrosion data shall either accompany the design specification or the specification will require soil resistivity measurements to be undertaken as part of the design process.

It is important to ensure that site measurements are taken prior to any construction work. The soil resistivity should be measured using the procedure described in the company's **Section E3 - Soil Resistivity Measurement**.

The measurement should:-

- be duplicated in different directions to provide an average
- cover the whole site area plus peripheries
- determine the likely layering of soil down to a minimum of 20 metres depth.

The soil resistivity data should then be used to produce a soil model using the CDEGSTM engineering software RESAP or equivalent. For a quick estimation of the EPR prior to creating a soil model see section 5 below.

5. DETERMINE Earth Potential Rise (EPR) (FIG.1. - STEP 3 & 4)

Using the average soil resistivity in Ω/m , obtained from the resistivity measurements, use the graph in appendix A to look up the resistance of a mesh grid for the area of the site being considered. Multiply the given resistance by the fault current I_e to give an approximation of the EPR. If the EPR is considerably greater 650v then it may save time by modelling the earth mesh described in section 7.1.

Otherwise layout a standard earth grid, as described section 5.1 below, and generate a model using the CDEGS engineering software MALT or equivalent.

The MALT software will determine the grid resistance using the soil model generated by RESAP. To obtain the EPR enter the zero sequence fault current provided into the MALT software. See the appropriate software manuals.

- If the EPR means the site can be classified as 'cold' then the design is satisfactory and a scale plan showing the layout and dimensions can be submitted.
- If the EPR means the site has to be classified as hot then continue to section 6.

5.1 Standard Earth Grid Layout

- (i) An outer ring of electrode conductor of copper tape should be shown, inside the fence line and a minimum of 2m away (inside) from any metal fencing. In addition, the electrode tape should be 1 metre outside any exposed metalwork of any plant within the substation. This means in practice, that the gap between any item of plant and the metal fencing should be a minimum of 3 metres. The outer ring should encapsulate an area as large as possible.
- (ii) Convert the outer ring to a mesh by plotting standard tape across the site, in two directions at 90° to each other, each tape being parallel to the outer conductor where practicable. The cross-members should form squares or oblongs, which should be spaced a nominal 10 metres apart and laid to a depth of 0.6 metres. They will be bonded to the outer ring and at each crossing point.

Some of the cross members should be laid in rows alongside plant to facilitate the connection of exposed metalwork to the grid. Great care must be taken when planning the grid layout to ensure that critical components such as transformer neutral connection points, switchgear earth bars etc., are provided with direct and duplicated routes to the perimeter electrode.

- (iii) At or near to the connection point of each cross member to the perimeter ring electrode, install one 2.4 m x 14.2 mm copper clad earth rod.
- (iv) Provision must also be made in the design of the grid layout to provide connection points for temporary neutral earth resistors required to replace the normal unit during maintenance, particularly if a resistor is to be shared between two or more transformers.
- (v) When a metal fence is used, the fencing must have its own electrode system. The 2m clearance between the fencing and the earth grid is to provide electrical separation between the two systems. Therefore any metallic pipes or cables which run under the fencing at a standard substation should be insulated in the ground for 2 metres either side of the fencing. Should the erection of any steel support columns for lighting or security cameras be intended, these must not be erected within this 2 metre strip.
- (vi) Copper tape size to be used:
 - 1. 132kV site - 40mm x 4mm
 - 2. 33kV site - 24mm x 4mm

6. CHAIN IMPEDANCE (FIG.1. - STEP 5 & 6)

To further reduce the EPR, account has to be taken of the contribution of any chain impedance from the tower footings or earthed poles connected to the site via a continuous earth wire. Engineering Recommendation S.34 recommends that the first twenty towers are taken into account. The resistance of the earth connection to ground at the towers should be modelled in the same way as modelling the grid. If the tower is in the same type of ground as the model produced in step 2 (section 4) for the grid, can be used. Having determined the typical footing resistance use figure 5 in Engineering Recommendation S.34 to determine the equivalent chain impedance.

The chain impedance is in parallel with the grid resistance (see figure 2). Whilst lowering the overall impedance of the fault path the resulting increase in fault current is negligible if the grid resistance is low in comparison with the source and line impedance.

Determine the fault current flowing through R_g with Z_{ch} in parallel, then enter it into the MALT model to generate the Earth Potential Rise and voltage profiles.

- If the Earth Potential Rise allows the site to be classified as 'cold' then the MALT output can be used in the final design report and the design process is finished.

OR

- If the Earth Potential Rise still results in a hot site proceed to Section 7.

7. TOUCH & STEP POTENTIALS (STEP 7)

Using the MALT model generated in section 6 determine if the step and touch potentials within the substation and around the fence, are within the following limits:

TABLE 2. MAXIMUM TOUCH & STEP POTENTIALS

Maximum Acceptable Touch Voltage (Et) :			
	Fault Clearance Times		
Fault Clearance Times:	0.2 seconds	0.35 seconds	0.7 seconds
On soil.	1050V	600V	195V
On chippings. (150mm)	1400V	800V	250V

Maximum Acceptable Step Voltage (Es) :			
	Fault Clearance Times		
Fault Clearance Times	0.2 seconds	0.35 seconds	0.7 seconds
On soil.	3200V	1800V	535V
On chippings. (150mm)	4600V	2600V	815V

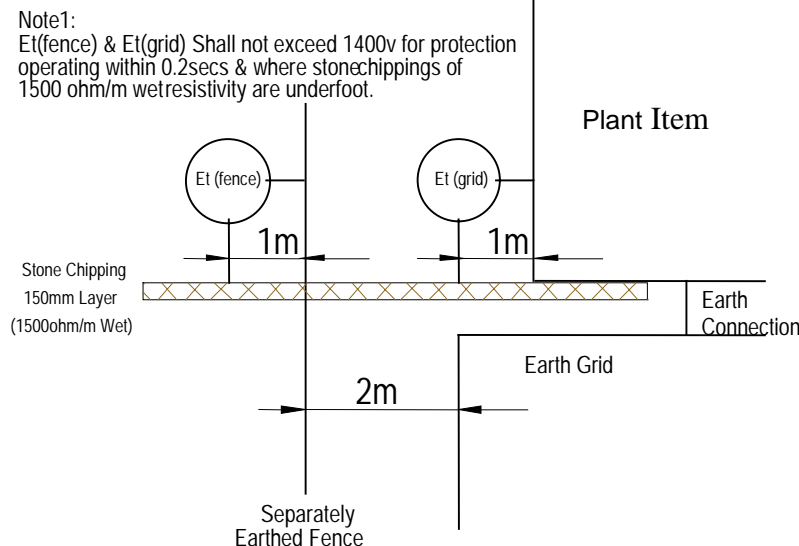


FIG.4. EXAMPLE - LOCATIONS FOR CHECKING TOUCH POTENTIALS

Note that the touch and step voltage limits used in the table above are based on E.A.T.S. 41-24.

If the touch and step voltages are within the above limits, then the design can be offered as an acceptable solution. The design needs to be discussed and agreed with the client as the Earth Potential Rise and resultant hot zone may exceed what they deem acceptable even though the touch and step potentials are within limits. East Midland Electricity's maximum acceptable Earth Potential Rise is 5kV.

If the Earth Potential Rise and/or the touch and step voltages are unacceptable the grid design needs to be amended. Before proceeding to section 7.1, which describes the requirements for an extended earth grid arrangement, the following options will assist in reducing touch potentials further:

- Provide "Faraday Cage" protection by laying an electrode 1 metre beyond and parallel to the fence, buried 1 metre deep, and connected to it. For a standard substation, this electrode must be kept segregated from the earth grid.

OR

- arrange for the affected section of the fence to be installed "earth free" by inserting an insulated fence section with insulated bushes at support positions and at any point where the fence is connected to an earthed section of fence.

OR

- provide a non-metallic barrier at this point, such as brick.
- It is essential that precautions are in place to ensure that third party fences are not connected to the metal substation fence, especially if the substation fence is bonded to the earth grid. Connection of a third party fence will introduce a transfer potential. Methods of overcoming this include providing a post near the corner of the perimeter fence, but separate from it, onto which third party fences can be connected. During regular maintenance, the inspection should include checking for connection of external fences.

7.1 Extended Grid Design (Fig.1. - Step 7b)

An extended grid substation is one where the earth grid has to extend beyond the substation, to reduce the Earth Potential Rise to below the 430V or 650V CCITT limit; or to limit the Earth Potential Rise and/or extent of the hot zone. The design will include the following features:-

- The perimeter of the earth grid will extend for 1m or more outside any metallic fencing.
- The metallic fencing will be connected to the earth grid in those areas where the perimeter conductor is beyond it.
- Metallic services (water) shall not be used within 2m of the perimeter fence or the declared hot zone, whichever is greater.

In some circumstances, where the substation has to be declared hot, there may be equipment (petrol filling stations, chemical plants or BT exchanges) nearby which may be prone to damage by rise of earth potential. It will be required to design the external electrode such that the hot zone contour avoids this equipment.

This design should be modelled in the MALT software and the fault current I_g should be recalculated if necessary.

If the result is a 'cold' design the design should be submitted and the process is then complete.

If the touch and step potentials are still in excess of the limits then further redesign is required; there are a number of options:-

- Provide "Faraday Cage" protection by laying an electrode 1 metre beyond and parallel to the peripheral conductor, buried 1 metre deep, and connected to it.
- Increase the number of conductors towards the outer edges of the mesh

Having arrived at a position where the touch and step potentials are within limits, the Earth Potential Rise will have been reduced. Agreement should be sort with the client that the Earth Potential Rise is acceptable.

If the Earth Potential Rise is acceptable the design process is finished and the final design can be submitted.

If the Earth Potential Rise is still too high, then proceed to section 8.

8. REDUCING Earth Potential Rise & HOT ZONE AREA (FIG.1. - STEP 8)

Since the Earth Potential Rise is a product of maximum earth return current and earth return network impedance there are several methods to reduce the Earth Potential Rise and hence the hot zone area.

These are to:-

- reduce the impedance of the earth grid,
- reduce the overall fault current; or
- divert more of the fault current away from the earth grid through parallel paths.
- In addition, the earth electrode (grid) can be designed to ensure that the hot zone contour is shaped to exclude sensitive/costly third party equipment.

See the 'Hot Zone Guidance Notes' document for a detailed description of hot zones and their implications.

8.1 Reduce the Grid Resistance.

The only effective methods are to either significantly increase the length of the earth rods (where there is low resistivity soil at deeper levels) or increase the area of the grid. For example, it may be possible to extend the earth grid into one or more sides of the site where this is acceptable.

Other alternatives, such as using greater cross section tape or more earth rods, will only provide a marginal improvement.

There are special back-fill materials which can be used which can sometimes be useful. The most common are Bentonite and Marconite. Bentonite consists of a clay which, when mixed with water swells to many times its own volume. It absorbs moisture from the soil and can retain it for a long time. Marconite is a conductive carbonaceous aggregate which, when mixed with conventional cement, effectively increases the surface area of the earth electrode, thus helping to lower its resistance.

These back-fill materials normally only provide a marginal improvement but may be specified for other reasons; for instance to help to maintain the resistance value at a more constant level throughout the year, or to provide protection against 3rd party damage - or to protect the electrode from corrosion. They are also useful for surrounding electrodes installed in rock.

Increasing the size of the grid may introduce practical problems and may also increase the area enclosed by the hot zone. Practical problems include obtaining the necessary wayleave and an increased risk of theft/damage.

8.2 Reducing the Impedance of Parallel Paths.

There are a number of possible alternatives:-

- lay earth conductor in outgoing cable trenches (assuming that the cables are PVC sheathed). If calculations show that this will make the substation “cold”, it is an attractive and economical solution. However, if the substation remains hot, it will extend the hot zone to include an area alongside the buried electrode some distance from the substation.
- ensure that maximum benefit will be gained from the impedance of tower footings by ensuring that aerial earth conductors are bonded to the tower steelwork at each tower position. In some cases additional earth electrode (e.g. a ring around the tower base) can be beneficial.
- it might be possible to take advantage of any deep excavation or piling, to incorporate these as part of the formal substation earth grid.

9. CONNECTION OF ABOVE GROUND PLANT AND USE OF METALLIC STRUCTURES.

Normally items of plant will be connected to the earth grid via copper or aluminium conductor. However, in many cases it is possible to use the aluminium or steel support structures. If concrete supports are to be specified, it is preferable (to avoid theft) for the above earth bond to be accommodated within a support. This can be achieved by a hollow duct/ channel or incorporating the aluminium / copper tape within the concrete during production.

Steel structures can be used in a similar way to aluminium to provide the connection between the earth grid and equipment on the top. However, shunts are required across each bolted joint position. Galvanising (zinc coating) of the steel forms an oxide which increases in thickness with age and could create a high resistance at steel - steel jointing surfaces.

A calculation is required to ensure that the steel has sufficient cross-sectional area and that the final temperature will not exceed 250°C for a bolted joint. Above a temperature of 419°C damage will be caused to the protective zinc. BS 7430 provides the following formula to calculate the area required, based on a starting temperature of 30°C:-

Mild steel current carrying rating for 1 second = 64 A/mm²

Assume current density = K amps (R.M.S) per mm²

Minimum cross-section area for 3 seconds duration is :

$$\frac{If \times \sqrt{t}}{k} = \frac{\sqrt{3}}{64} \text{ Kg/cm}^3/\text{m}$$

where k is 64 (see table 8, BS 7430) i.e. the density of mild steel = 7.85 x 10⁻⁶ Kg/mm³

10. EARTHING OF OVERHEAD LINE TERMINATIONS AT SUBSTATIONS.

10.1 Tower Lines

Terminating at a substation with a standard earthing arrangement.

The tower line aerial earth conductor should be bonded to the tower at each tower position. If the terminal tower is situated outside the substation the tower should be connected to the earth grid, and for security reasons, this connection should be duplicated. Normally this will be provided by running a loop of standard copper bare tape, 1m deep, and 1m outside the tower footings, from two different points on the perimeter electrode. Two of the tower footings should be connected to this loop. This arrangement is shown in Figure 5 and will help reduce the overall earth impedance. If the tower is a significant distance from the substation (more than 50m), special arrangement may be necessary and a specialist earthing design engineer must be consulted.

The copper tape or conductor forming the loop around the tower base needs to be insulated where it runs within or through a corridor 2m either side of metal perimeter fencing. The arrangement is shown in Figure 5.

If the terminal tower is situated within the substation, two tower legs are to be connected to adjacent earth grid conductors. If a terminal tower is within 2m of the fence, then the fence near the tower will need to be either insulated or bonded to the tower and separated from the rest of the fence via insulated bushes on either side.

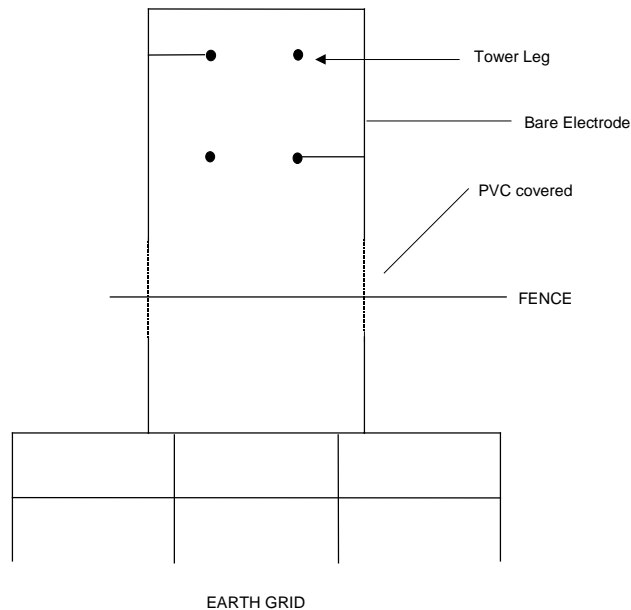


FIG.5 EARTH CONNECTION TO TERMINAL TOWER.

10.2 Terminating at a substation with a non-standard earthing arrangement.

The arrangements are the same as for a standard substation except that it is not necessary to insulate any copper tape or conductor which runs through or adjacent to metal perimeter fencing. This is because the fence is bonded to the earth grid. Also, terminal towers can be within 2m of the fence.

10.3 Wood Pole Lines.

Each terminal stay of any wood pole line should have an insulator fitted into the stay. The steelwork on the pole top is to be bonded to the main earth grid. Where Paper Insulated Lead/Aluminium Sheathed three core cables are used, then the cable sheath may be used to provide the earth connection. Where XLPE cables are used, a separate earth connection is required.

Any buried electrode must be insulated where it runs within or through a corridor 2 metres either side of the separately earthed metal fence, but not if the fence is bonded to the earth grid (non-standard arrangement).

10.4 Terminal Stays.

The general principles are that:-

All stays have an insulator fitted.

All stay top sections on are bonded to the pole top steelwork.

All stay rods and bottom sections situated within the area encompassed by the earth grid or less than 2m beyond it, are to be bonded to the main earth grid.

The above will adequately cater for the majority of situations. However, where a stay is positioned close to a separately earthed perimeter fence, the bottom section of staywire may provide a means of breaching the 2m separation between the fence and equipment bonded to the earth grid. In this case a second insulator may be required, just above the stay rod. This will leave the middle section of the staywire unearthed and ideally, if practicable, this should be enclosed within PVC sheathing, (heat-shrink or similar).

If a stay rod associated with any terminal stay enters the ground within 2m of the earth grid, the stay rod should be connected to the earth grid using standard electrode. If the stay position is within the main earth grid, then a single connection to the grid is sufficient. If it is not, then a further ring of electrode should be laid at the base of each such stay, a radius of approximately one metre away from the point at which the stay rod enters the ground. This ring of conductor should also be connected to the earth grid.

Any buried electrode should be insulated where it runs within a corridor 2m either side of a separately earthed fence, but not if the fence is bonded to the grid (the non-standard arrangement).

11. EARTHING OF UNDERGROUND CABLES WITHIN SUBSTATIONS.

Inductive interference in these cables arises due to high frequency surge currents on the main power system components within the substation. These high currents create magnetic fields which encompass nearby cables and cause inductive interference. It is important that precautions are taken to limit transients on these cables to acceptable values. The basic precautions to be taken are :

- (a). Route duplicate control and communication cables in separate radial directions, if possible. These cables should preferably not be run in parallel.
- (b). Ensure that supply and return cores are within the same cable, as otherwise significant interference can result.

- (c). Control, communication, current and voltage transformer secondary circuits all require an earthed outer non-ferrous sheath. For substations at 132kV and below, the sheath shall be connected to earth at one point only (normally at the control panel position).
- (d). Control cable runs should be at right angles to high voltage busbars, wherever possible. If they must run in parallel, then the length in parallel should be a minimum and the separation from the busbars as large as possible. Where cable sheaths are earthed at each end, it is preferable for these cables to run close to and parallel with electrodes of the main substation earth grid, as this further reduces the longitudinal impedance between the ends of the sheath.

12. EARTHING OF CABLES (POWER, TELECOMMUNICATIONS AND CONTROL).

All exposed metalwork within a substation shall be connected to the earth grid. This includes the metal sheaths of cables, either laid within the substation or laid to connect with the external network. However there are a number of different ways of earthing cables, depending on the type, route, etc.

These paragraphs describe bonding/shrouding requirements, in general terms, according to the voltage and type of cable. For detailed information, reference should be to Electricity Association Recommendation C55/4.

Note that, where switchgear has frame leakage protection installed, the earth connection from cables must be to the main substation earthing system, i.e. on the remote side of the frame leakage CT's. These connections must be insulated to prevent contact with the switchgear metalwork.

12.1 132kV and 33kV Power Cables

- (a) Three core hessian covered steel-wire or tape armoured cables.

The lead sheath/armouring has to be bonded together and connected to the earth grid. If the cable is less than 25m in length, then it is adequate to bond it at the switchgear end only although earthing at each end is preferred. If longer than 25m it shall be earthed at each end.

- (b) Three core insulated sheath cables.

The metallic sheath must be bonded to the substation earth grid. Normally the sheath is bonded at the switchgear end and at the remote end. (At sealing ends, this will be via 120 mm sq. stranded copper conductor, PVC covered, in accordance with BS 6364). Care is required when the cables terminate in a separate, nearby substation, because if both ends of the cable are connected to earth, the cable sheath will interconnect the two earthing systems. If it is intended that the two earthing

systems are to be interconnected, then formal earth connections between them are necessary in addition to the connection provided by cable sheaths.

(c) Single core cables.

Where single core cables are used, the method of connecting to earth must be specified by the design engineer. The metallic sheath must be earthed because otherwise its potential could rise to that of the phase conductors. For relatively short cables, it is normal practice to connect the three single core sheaths at one end. The other ends of the cables would normally be insulated and shrouded, possibly with a voltage limiting device fitted. The sheaths would normally be connected to earth at the end where they are bonded together. In some cases a PVC covered earthwire is laid alongside the cables and instead of being connected to earth at one of the ends, the sheaths may be connected to this earthwire at its mid point position. The earthwire is connected to the substation earth grid. When laid alongside single core cables, the earthwire helps to reduce the electrical interference which arises when earth fault current passes through one of the cores. The ideal distance for the earthwire depends on the single core cable formation (e.g. flat or trefoil) and spacing. For longer single core cable runs (typically greater than 1km) transposed cross bonded earthing is used.

12.2 11kV Cables

Most existing 11kV cables have either a hessian covered steel-wire (or tape) armouring, with a lead sheath; or are PVC served with an aluminium sheath. Polymeric type cables are now increasingly being used and have a stranded copper sheath and a medium density polyethylene outer serving (MDPE). It is important that the sheath cross sectional area is sufficiently large to carry the anticipated fault current and not to have too high a longitudinal impedance. These cables are normally terminated on switchgear via an insulated elbow connector or heat shrink connection. In either case, the sheath and armours are to be connected to the main substation earth bar, normally via a flexible tape or braid connection. The tape/braid should be long enough to pass through the CT of a fault passage indicator or automation transmitter. Where frame leakage protection is used, there will also be a switchgear earthing bar which is connected via a CT to the substation earth. Cable sheaths must not be connected directly to the switchgear earth bar when frame leakage protection is fitted.

A bare copper stranded earth conductor of 50mm^2 cross-sectional area is to be laid with each out-going group of insulated sheath cables for a minimum distance of 75 metres from the substation (unless deemed not required by the Design Engineer). In the absence of more specific design guidance, the total length of bare earthwire installed in this way at a ground mounted substation is to be $3.2 \times$ the soil resistivity value, metres. (e.g. if the soil resistivity is 75 ohms/metres then $75 \times 3.2 = 240$ m of earth wire is required).

The conductor required should be shared equally amongst the number of parallel routes. The electrode should be laid at the bottom of the trench, with approximately 150 mm soil cover between it and the nearest power cable. The electrode is to be insulated for 2 metres either

side of any metallic boundary fence which has its own independent earthing arrangement. These earth connections shall be connected to the main substation earth bar and be labelled and capable of disconnection should any subsequently not be required. These radial earth electrodes will reduce the earth resistance value towards 1 ohm, help stabilise it during the year and provide a degree of security against it rising significantly if hessian served cable on the network is removed.

12.3 Low Voltage Cables.

- (i) Cables used exclusively for “in house” supplies.

The sheaths of these cables must be bonded to the substation grid.

- (ii) Cables used for supplying external loads.

L.V. cables for which the neutral/earth connection is within the substation, shall not be used to supply customers outside if there is any possibility of the substation Earth Potential Rise exceeding 430V/650V (as appropriate).

For similar reasons, “in house” supplies to a substation shall not be provided direct from an adjacent L.V. network if there is any possibility of the substation Earth Potential Rise exceeding 430V/650V (as appropriate).

12.4 Telecommunication and Pilot Wire Cables.

12.4.1 Introduction.

Telecommunication and pilot cables laid with power cables, or supported on overhead lines of high voltage circuits, are subject to induced voltages from fault currents in the higher voltage conductors. The level of induced voltage can be high, particularly in cables laid with 132kV or higher voltage cables. The induced voltage is itself calculated taking into account physical separation from the power conductors, the level of inducing current and the type of screening. Because of possible danger to operational staff, special care must be taken when working on cable terminations of telecommunication and pilot wire circuits, especially at the earth connections. A safe operating procedure may be required for working on the cores of these cables. Additional precautions may be required where cables are supported on overhead lines subject to high induced voltages. Overhead pilots may also be earthed at joint positions.

A safe working procedure is required for work on the cable cores when the induced voltage in the cable can exceed 430V or 650V, as appropriate. This is normally based on links which are rated above the induced voltage level (5kV or 15kV). These are withdrawn prior to touching cores within the substation. Before reinserting them, insulated voltage measuring equipment and insulated gloves are required.

Some cables must be insulated from the substation earthing system for barrier purposes. For example, cables which bring information from 132kV cable joints (gas or oil pressure alarms)

may be earthed at the joint position. They are insulated within the substation and the cable termination shrouded to prevent touching.

12.4.2 Telecommunication Cables.

At major substations these cables are terminated via isolation links and/or isolation transformers or by other methods specified in the company telecommunications policy. These cables generally have an insulated outer sheath. Depending upon the policy adopted, the sheaths may be earthed at one or both ends. For those circuits where the telecommunication cables are subject to excessive induced voltage, the terminal boxes need to be of a special design.

12.4.3 Pilot Cables

The sheaths of pilot cables must be insulated from the earth grid and terminated via insulated gland connections. Great care must be taken to maintain this insulation. The cable sheath will be earthed at one or both ends, depending on company telecommunications policy. If at one point, this will normally be at one of the end substations.

13. EARTHING ARRANGEMENTS APPLICABLE TO 400/275/132kV SITES

Where there are adjacent 400kV, or 275kV and 132kV sites, then NGC will be responsible for designing and installing earthing on the 400 or 275kV site, and the Company will be responsible for designing and installing earthing at the 132kV site. Consultation should take place between the two companies at the earliest opportunity to agree on the arrangements for bonding the two systems together. The earthing system should, preferably, be designed as an overall entity, with provision for strong interconnection between the sites, to minimise any potential differences that would occur and to make the best use of available land area. Each company should then "fine-tune" their individual designs to meet their own requirements.

Back up LV supplies are required at these substations and would normally be provided via the LV or 11kV network. The nature of the earth connection provided needs to be considered, especially if the "Supply Point" or "Grid Supply Point" is hot, as it is not desirable to transfer this onto the lower voltage network.

14. EARTHING ARRANGEMENTS APPLICABLE TO SITES WITH GENERATION

Conceptual earthing of generating plant is covered in Electricity Association Technical Standard 113, Electricity Association G59 and Electricity Association G59/1. These should be referred to for practical guidance on earthing the generators themselves.

The following guidance is provided to deal with design of the electrode systems until such time that the subject is addressed by European or National Standards. Where generation plant

is to be situated adjacent to or within a substation, it is essential that the earthing system is designed to a similar specification to that of the substation and any requirements of the external connected network. The same general design rules as set out previously in this document will apply, especially the touch and step voltage limits. Where appropriate, declared LV earth loop impedance values should be maintained.

However, additional studies will be required at the design stage to ensure that the impedance of the earthing system interconnecting the generator earthing to that of the rest of the site is sufficiently low as to prevent undesirable potential differences.

Earthing of wind farm collection substations provided by the Company should be in accordance with the appropriate part of this earthing document and comply with EA Electricity Association Technical Standard 41-24. Where wind company substations or plant is situated adjacent or within a Company substation, this shall be to a similar specification.

Earthing of wind farm generators themselves and the overall wind farm is a specialist subject and beyond the scope of this document. Normally rod arrays are required at each generator to provide lightning protection in accordance with BS 6651 and potential grading may also be necessary. Because of the size of the electrode system, calculations taking into account longitudinal impedance are normally required.

15. EARTHING ARRANGEMENTS AT BRITISH RAIL SUBSTATIONS

Generally British Rail Substations are supplied via 132/25kV single phase transformers. The arrangements should comply with Electricity Association P.24. It should be noted that, at these locations, there are significantly large earth return currents.

Refer to **Section E6 - Protective Multiple Earthing** for the special requirements for providing low voltage supplies to line side equipment, stations and buildings.

16. EARTHING ARRANGEMENTS AT GAS INSULATED SWITCHGEAR SUBSTATIONS.

This type of equipment is very compact and occupies a small area of land, typically only 10% to 15% of that required by conventional outdoor air insulated equipment. The reduced area available usually places an immediate limit on the earth resistance value which can be achieved practically. However, there are additional factors associated with Gas Insulated Switchgear (G.I.S.) which considerably complicates the design task. These are as follows:

High fault current. Because of the expense of G.I.S. equipment, it is normally used at higher voltages. The earth fault current at these voltages is high - typically 20kA or more, and this places an onerous demand on the earthing system. In some cases, 33kV G.I.S. equipment is used and the earth fault current is limited to 3 to 5kA by impedance earthing.

Residual AC current. GIS equipment uses earthed metal screens around individual phase conductors. Current is induced in these screens and a residual AC current is likely to flow

continuously via the earthing system. There is presently concern that these AC currents may cause accelerated corrosion, particularly in steel electrodes.

High frequency currents. The nature of the equipment means that switching transients can occur whilst electrical currents are being interrupted. These transients include components at very high frequencies. Some flow within the confines of the local earth grid, whilst others flow into the ground. The electrode system to deal with high frequency current flow into the ground is different to that for 50 Hz operation. The most often quoted solution is to increase the density of the earth electrodes in the immediate vicinity. However this needs to be accompanied by specific screen terminating arrangements and secondary control wiring needs to be routed to minimise inductive interference. The design seeks to ensure that high frequencies are confined to the inside of screened enclosures, but the presence of interfaces (such as at air terminations, insulated CT flanges and transformer bushings) allow some opportunity for these to escape.

It is also important to ensure that the earthing design does not permit circulating currents to flow between plant and connections, which would cause interference. Design of the earthing system for G.I.S. equipment is thus a particularly challenging task and on-going research should result in improved earthing arrangements.

It is normal to provide a significant number of vertical earth rods close to the GIS enclosure, indeed some rods may pass through the floor into underlying soil such that an earth is provided as close as possible to the equipment. It is also common to have a copper mesh electrode embedded in the buildings concrete floor and all equipment is connected to this via short, vertical spur connections.

Connections between plant are run close to and parallel with earth mesh conductors. G.I.S. equipment is generally earthed via vertical rods, which are connected to the internal mesh near the following equipment locations, to disperse externally referenced currents :

- close to circuit breakers,
- close to cable sealing end,
- close to the SF6/air bushing,
- near to instrument transformers,
- at each end of the busbars, and at intermediate points (for long busbars).

The plant earth connections to an internal grid which has conductors of relatively small cross sectional area should be distributed by additional connections forming a cross or star type arrangement until sufficient grid conductors are bonded to carry the required current. The connection must not be to a single conductor or a few small conductors.

17. EARTHING ARRANGEMENTS FOR SURGE DIVERTERS AND CAPACITOR VOLTAGE TRANSFORMERS.

Switching transients from the high voltage system will see a Capacitor Voltage Transformer (CVT) as virtually a short circuit to earth and will flow through it with little attenuation. The bonding connection and the in-ground electrodes need to be designed to cater for this. In a similar way, the current flowing through a surge diverter under fault conditions is not sinusoidal and when transformed into Fourier components, it has a waveform which is made up of high frequency components.

The connection from the CVT or surge diverter to earth and the electrode system itself has an impedance which is predominantly resistive but also has an inductive component. This inductance is especially important at higher frequencies where the inductive component of the subsequent voltage rise may be considerably higher than the resistive component. This effect can seriously reduce the efficiency of the surge diverter and hence the system of insulation co-ordination. In CVT's, where a high frequency electrode may not have been installed, companies have experienced flashovers across CVT low voltage wiring glands. To counteract this, special earthing arrangements are necessary. For example, the conductor which connects the earth of the device to the earthing system must be as short and straight as possible.

Two connections are required for these devices. The first is a standard bond from the frame, through to the main earth grid. The second is a high frequency earth connection which should be as straight as possible, through to an earth rod which is as close as possible to the equipment being protected. Only for 11kV and 33kV pole-type surge diverters can the two connections be combined into one earth electrode.

When seeking to achieve a particular impedance value, the electrode system for high frequency currents will need to be designed differently to that for normal frequency currents. This will require more vertical electrodes close to the structure.

18. SITING OF METAL SUPPORTS FOR SECURITY LIGHTING ETC.

It is becoming common practice to install security lighting and/or camera's on metal support columns inside substation compounds. It is essential that staff be protected against the possibility of excessive touch potential. Preferably these items and the supply to them should be referenced to the substation earth. To achieve this, the column must be sited a minimum distance of 1 metre inside the outer conductor of the earth grid. For a standard substation, this means siting the column a minimum distance of 3 metres from the fence line. Where this distance cannot be achieved then a non-metallic support pole should be used, such as wood, plastic or fibreglass. In this case, the use of metal ladders is not permitted on the fence side of the structure as they could bridge the gap between the fence earth at ground level and equipment at the pole top which is referenced to the substation earth.

Where the substation earth grid extends outside the substation perimeter fence there is no problem siting a metal support anywhere inside the substation, subject, of course, to normal clearance requirements to uninsulated overhead conductors.

Any metal support must be bonded to the grid, and the low voltage supply must come from the “in-house” supply. Barrier equipment is required in cables or wiring to remote locations to prevent any potential on the substation earthing system being transferred there, if the substation is hot.

Construction staff must consult with the design staff before erecting metal support columns inside a 132kV or 33kV substation.

19. COMMUNICATION FACILITIES

Because of the high frequencies involved, a different earthing grid design is required. This attempts to maximise the amount of conductor in the immediate vicinity of the structure. For example, at a microwave dish or large aerial, it is normal to have a number of parallel earth down leads near the base of the structure, each of which terminate in an earth rod. This reduces the overall impedance. The mast itself will normally carry most of the fault/lightning current down to the base, even if down leads are fitted. Electrodes which run out radially, are relatively close together and arranged symmetrically may be used in addition to rods. For further details, specialist advice should be sought.

Where (as is usually the case), the communication facility shares the same site as a substation, then the two earthing systems would normally be well interconnected. Particular attention is required to the bonding/termination of pilot and communication cables and the earthing arrangement for the LV supply. The substation earthing system will be especially important in the event of a lightning strike to the communication tower as it will help disperse the energy associated with this. The overall design should seek to minimise any potential difference across the earthing system during the strike.

20. REACTORS AND AC TO DC CONVERTERS.

Normally there are high electro-magnetic fields associated with such devices. These can, in turn, induce high currents in any nearby metal structures or earth conductors. Additional precautions are required to prevent induced circulating currents. One method is to ensure that such equipment is only earthed at one point. Another solution is to use non-metallic fencing or supports in close proximity to these devices. Where thyristors are used, again high frequency harmonic currents may be present and the earth electrode may need to be positioned close to their source to prevent significant potential differences arising.

Interconnecting leads to other equipment should be run close to earth grid conductors.

21. SUBSTATION SURFACE COVERING MATERIAL.

The open surface areas of the substation shall be covered with insulating material (stone chippings) to the specification detailed below. The specification is included in this section on substation design because it is an integral part of the substation earth system and ensures that the touch and step potentials listed in table 2, section 7, can be used with confidence. Where

the site is hot it may be necessary to lay chippings around the external perimeter fence, typically to a width of 1.5 metres. In order to reduce future maintenance and to ensure the integrity of the insulating properties it is beneficial to cover the surface with a porous matting to restrict weed growth, prior to laying the chippings.

21.1 Surface Material Specification

It shall consist of particles of screened crushed gravel or rock with the percentage of particles having two or more fractured faces being 60% or greater.

The material shall conform to BS 63 Part 2. The particles shall be hard, durable, inert, free of soft shag flakes, pyrites or other metallic compositions.

Gravel or rock shall conform to the following gradation:-

Sieve designation	Percentage passing by weight
25mm	63 to 100%

The minimum wet electrical resistivity value of insulating gravel or rock shall be 1500 ohm metres and before being placed on site, the minimum wet resistivity shall be established by testing.

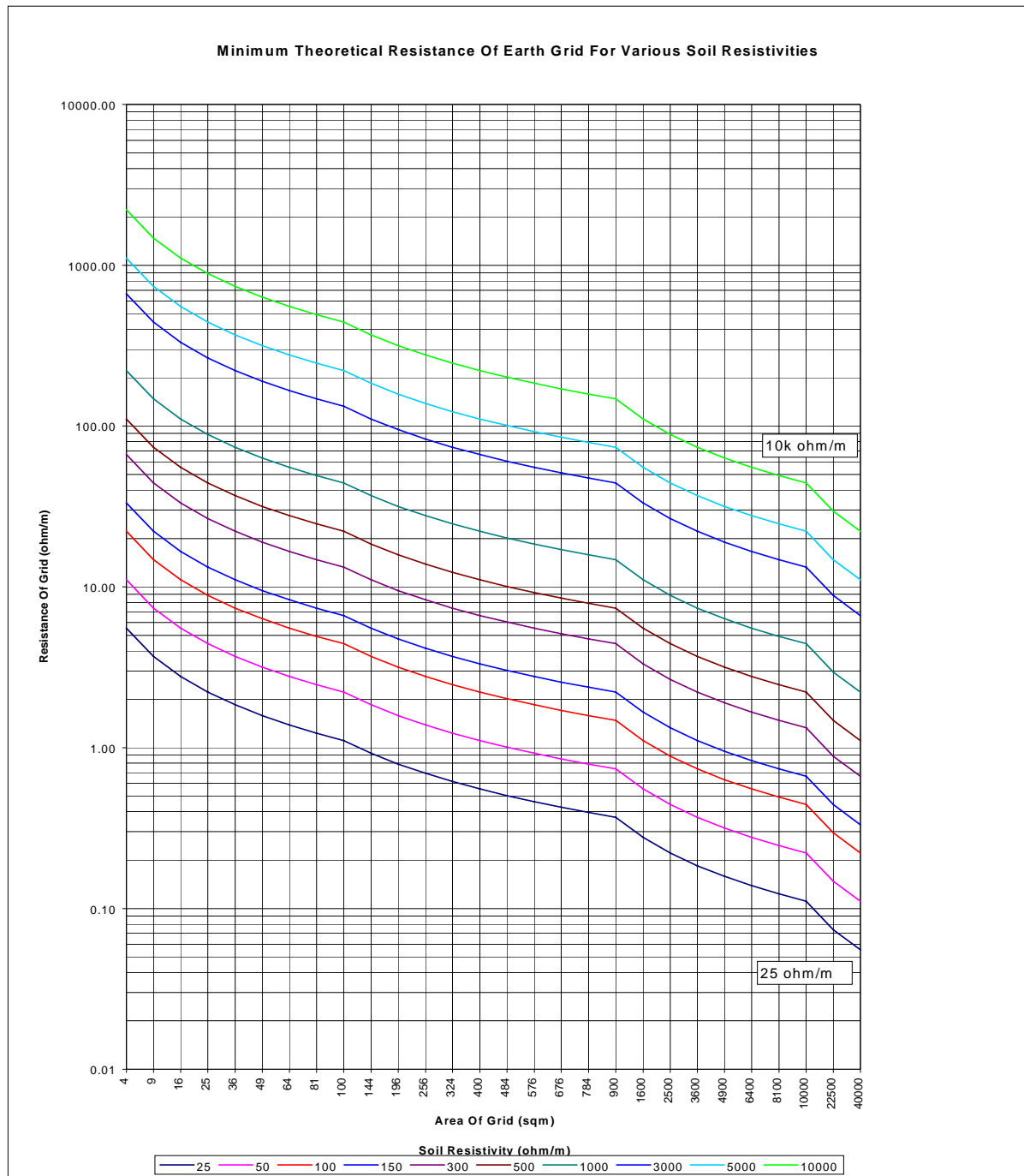
As a general rule, the following materials are suitable for insulated gravel or rock.

- Limestone
- Quartzite
- Granite.

Materials such as shale or granulite are not suitable as their resistivity falls significantly when wet.

22. APPENDIX A - EARTH GRID RESISTANCE GRAPH

The graph below shows the minimum theoretical resistance of a mesh grid for different soil resistivities and grid area. This can be used as a quick guide as to determine the value of Earth Potential Rise of the grid. Having established an equivalent soil resistivity from the site measurements the grid resistance can be read off the y axis for the grid area under consideration along the x axis. The resistance can then be multiplied by the fault current to give the Earth Potential Rise.



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Section E9

132/33/11kV & 33/11kV

Earth Grid Design Specification

Database Ref: 58	File Ref: Section 9 Earth Grid Design Specification Jan2001	Manual Name: Earthing Manual
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Version	Prepared by	Approved by	Issue Date
1	Tony Haggis	See Database	02/2001

Revision Log For Section E9 132/33/11kV & 33/11kV Earth Grid Design Specification

Changes made in version 1	
Section	Notes about the change
E9	First Issue

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1. GENERAL

The tenderer will supply an earth electrode design detailing the physical layout and dimensions of the earthing system, showing the hot zone contour if applicable.

The earth grid design shall provide for the following functions:

- (a) Provide a low impedance path to enable fault current at any point on the electrical network to be returned to the transformer or generator neutral(s), without thermal or mechanical damage to connected apparatus, and to enable protective equipment to operate correctly.
- (b) Limit voltage rises, on all metalwork and the surface of the ground to which persons have normal access, to a safe value under all reasonably perceived conditions. The earthing system should be so constructed as to prevent the establishment of dangerous potential differences between parts of the substation that a person may be contacting simultaneously.

2. TECHNICAL SPECIFICATIONS

The earth grid design will comply with:

- Electricity Association Technical Specification 41-24 - 'Guidelines for the design, installation, testing and maintenance of main earthing systems in substations'.
- Electricity Association Engineering Recommendation S.34 - 'A guide for assessing the rise of earth potential at substation sites'.

3. EARTH POTENTIAL RISE

Where site conditions are suitable, the maximum allowable earth potential rise, to enable the site to be classified as 'cold', will be:-

132/33kV Substation - 650 volts

33/11kV Substation - 430 volts

Where site conditions are not suitable for a 'cold' site, the maximum earth potential rise allowable will be 5kV.

The overall impedance to earth at a major substation will consist of the combined impedances, in parallel, of the earth grid, the chain impedance of any steel tower lines, together with the impedance to earth of any connected cables.

4. HOT AND COLD DESIGN

A preferred earth grid design arrangement will provide a 'cold' substation. The design will include the following features:-

- The earth grid will be contained inside the substation fenced area, with its perimeter electrode a minimum of 2m away from any external metal fencing. The grid will extend a minimum of 1m beyond plant metal work. In effect this will provide a separation distance of 3m between the separately earthed fence and any exposed metalwork enclosed by the fence.
- Any metal fencing will require its own earth electrode system that is to be electrically segregated from the earth grid, i.e. positioned at least 2m away from the grid.

An extended grid substation is one where the earth grid has to extend beyond the substation perimeter, to reduce the Earth Potential Rise to below the 430V or 650V limit; or to limit the Earth Potential Rise and/or extent of the 'hot' zone. The design will include the following features:-

- The perimeter of the earth grid will extend for 1m or more outside any metallic fencing and will be connected to the main earth grid. The metallic fencing will not have a separate earth. The fence will be earthed directly to the main earth grid at each corner position and at the mid-point along each side.
- Metallic services (such as water) shall not be used within 2m of the perimeter fence or the declared 'hot' zone.

Where the substation has to be declared 'hot', and there are installations, such as petrol filling stations, chemical plants or BT exchanges, nearby which may be prone to damage by rise of earth potential, the external electrode must be designed such that the 'hot' zone avoids these installations.

5. MAXIMUM TOUCH AND STEP VOLTAGES.

The maximum acceptable touch voltage is 1400 volts, assuming a protection clearance time of 0.2 seconds and a surface of 150mm chippings with a minimum wet electrical resistivity of $1500\Omega/\text{m}$.

The maximum acceptable step voltage is 4600 volts, assuming a protection clearance time of 0.2 seconds and a surface of 150mm chippings with a minimum wet electrical resistivity of $1500\Omega/\text{m}$.

6. SOIL RESISTIVITY MEASUREMENT

The earth grid design will be based on soil resistivity measurements made at the proposed substation site. The following items will be submitted with design.

- An assessment of the soil's corrosive properties with respect to copper.
- A soil model, produced using available propriety software*. The results of the soil model will be used to calculate the resistance of the earth grid design.

* CDEGSTM earthing analyse software which is the package currently approved by East Midland Electricity. Visit <http://www.sestech.com> or e-mail info@sestech.com Other packages may be used with the prior approval of the East Midland Electricity Equipment Specialist .

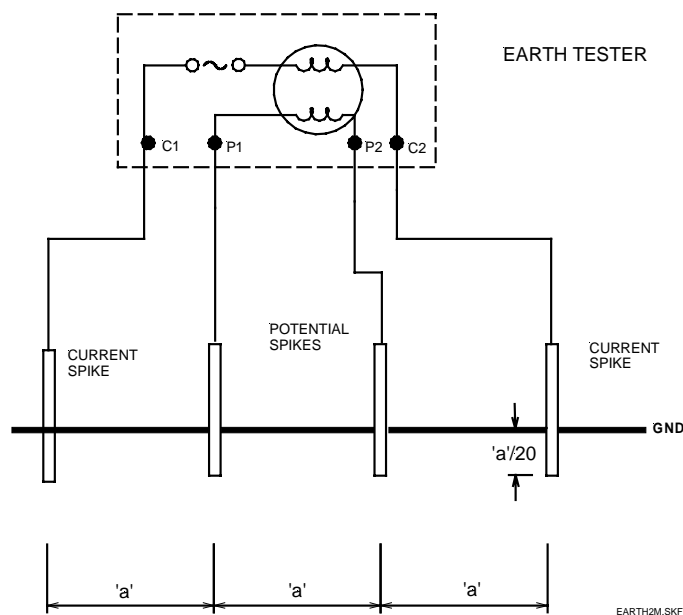
6.1 Measurement Specification

There are numerous methods of carrying out soil resistivity measurements. The following specification is recommended although alternatives may be used. If an alternative is used documentation describing the method shall be submitted.

The route chosen for the tests should preferably be in undisturbed soil, away from any known cable/pipework routes, and at least 10m away from the boundary of an EHV substation. Readings are to be taken at the different values of 'a' shown in Table 1. Note that it is important to ensure that measurements are symmetrical about point X, midway between the voltage rods. The test should be repeated at approximately right angles to the first set.

If there are large fluctuations in the measured values between the two sets of readings at the same spacing, then it is likely that interference from buried cables/pipes or stray ground currents are present. Additional sets of readings must be taken at locations a few metres away. If the problem persists, then measurements at a more distant, representative site are required.

Fig.1. shows the general measurement arrangement. The four earth rods should be driven into the ground in a straight line, at a distance 'a' metres apart and driven to a depth of 'd' metres. The actual dimensions are given in Table 1.

**FIG.1. SOIL RESISTIVITY TEST****TABLE 1. PROBE SPACING AND DEPTHS**

Applicable to Installations Up to	Probe Spacing 'a' Metres	Probe Depth 'd' Metres
11kv	0.5	0.02
	1.0	0.05
	2.0	0.05
	3.0	0.10
	6.0	0.10
	9.0	0.10
	14.0	0.10
	18.0	0.15
	22.0	0.15
33kV	25.0	0.15
132kV	50.0	0.20

The four rods are connected to the tester, as shown in Fig.1., with the outer rods connected to the C-1 and C-2 terminals, and the inner rods to the P-1 and P-2 terminals. At each spacing measure and record the instrument reading.

Note: On most earth resistivity tester terminals C1 and P1 can be shorted to enable the instrument to measure electrode resistance. Ensure these two terminals are not shorted out whilst carrying out a resistivity test as you will get a false reading.

7. DRAWINGS

The earth grid design shall be shown on a scale drawing of the proposed layout of the substation site. This drawing or a copy should be used to show. This drawing may also be provided in electronic DXF (Autocad) form.

8. SYSTEM INFORMATION - PROVIDED BY EME

The following information will be required by the tenderer:

1. System three phase short circuit level (I_f).
2. Zero sequence earth fault current (I_e).
3. Scale plan showing substation layout.
4. Configuration and impedance of cables or lines connected to the substation.
5. Configuration and impedances of transformers and neutral earth impedances.
6. Data to enable a soil model to be produced, (unless requested to carry out substation site soil resistivity measurement).
7. Tower dimensions, and footing resistance, or soil resistivity measurement data to enable a soil model to be produced. Where applicable this will allow the tower chain impedance to be determined.

This information may have to be obtained by the tenderer or by East Midland Electricity depending on the terms of the contract.

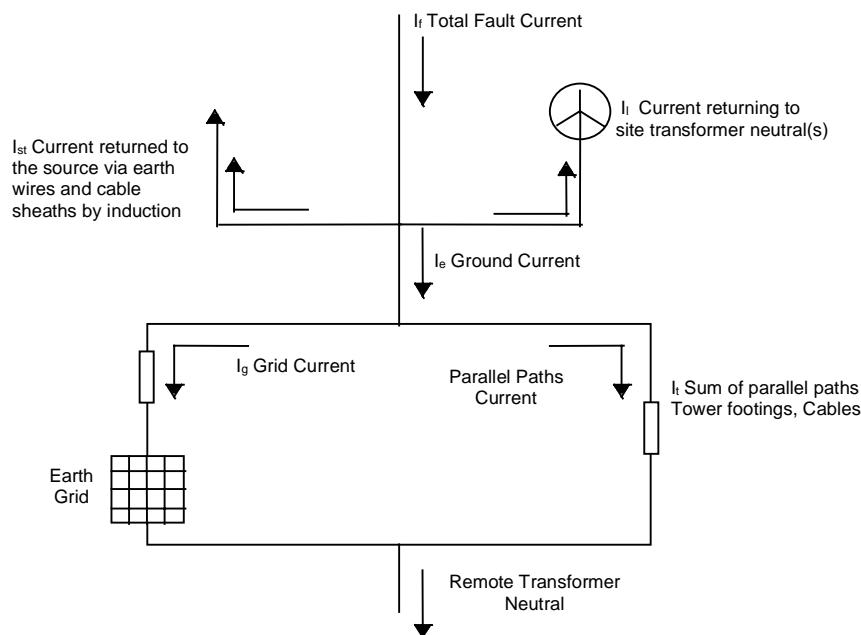


FIG.2. FAULT CURRENT PATHS ASSOCIATED WITH 132KV SUBSTATION

Section E10

Hot Zone Guidance Notes

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FIGURES

FIG.1. POTENTIAL CONTOURS ON SOIL SURFACE AROUND EARTH ROD.	4
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1. Introduction

A hot zone is the area surrounding a electrical plant where the rise of earth potential, under maximum earth fault current conditions, can exceed the value specified in Electricity Association Technical Specification 41-24. The values given are:-

Circuits with standard protection	430 volts.
High reliability circuits with high speed protection. i.e. can clear an earth fault within 200 milliseconds	650 volts.

As a general rule, the 650V value would only normally apply to 132kV and higher voltage equipment and to some 33kV equipment.

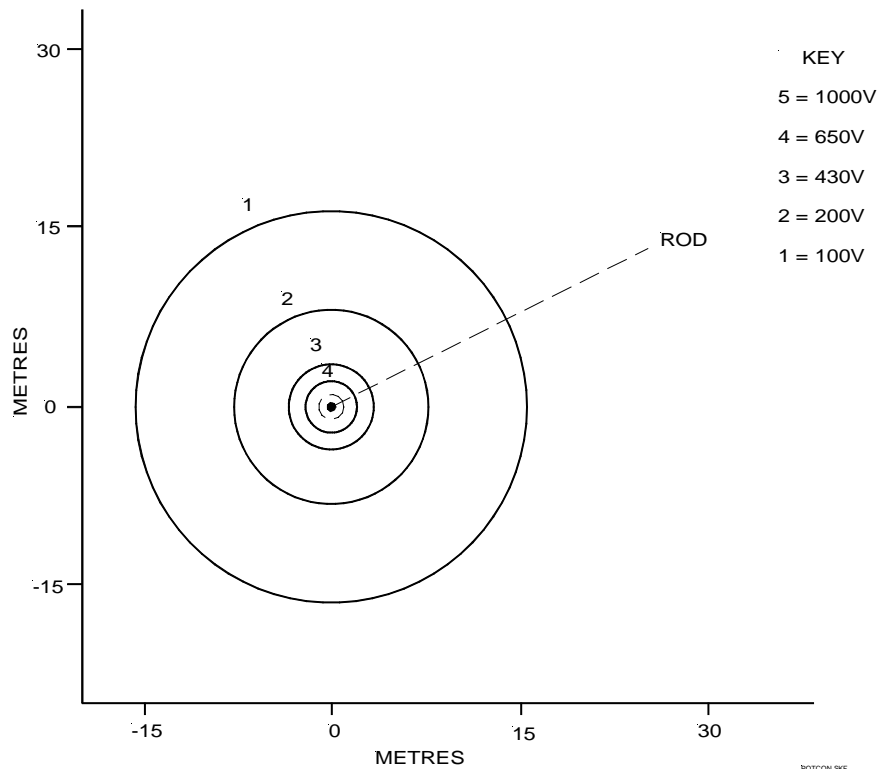


FIG.1. POTENTIAL CONTOURS ON SOIL SURFACE AROUND EARTH ROD.

The potentials on the surface of the soil, in figure 1, around the earth rod have been represented as equipotential lines. This is the same effect as would occur for a substation, except that the lines would follow the shape of the electrodes installed, so would not normally be circular. If the rise of earth potential (EPR) at the substation exceeds the 430/650V limit, then the equipotential line coinciding with the 430 or 650V contour would need to be identified. The area within the substation and up to the appropriate contour line is known as

the hot zone. Special precautions are necessary where there are any metallic services or structures situated within this “hot-zone” area.

1.1 Implications of a Substation being Hot

The immediate practical requirements are:

- An isolation transformer is required where the telecommunication service(s) enters the substation building.
- All metallic services to the site and building require attention to ensure they do not introduce a transfer potential risk. This can be prevented by introduction of insulated inserts (normally one inside the substation and another 2m beyond the perimeter fence). Alternatively, the water supply could be provided by a plastic pipe from 2m outside the perimeter of the substation. Any exposed metal of services must be bonded to the substation earth grid if there is any possibility of simultaneous contact.

Where the final arrangements mean that a substation will have a hot zone, there are a number of steps which need to be initiated which in brief are :

- (i) BT or other telecommunication companies who use metallic cables, need to be advised. They will require telecommunication cable in the substation to be terminated via an isolation transformer (possibly at East Midland Electricity's expense) and may require additional insulation or protective measures on any equipment which passes within the hot zone area.
- (ii) Other Bodies (Gas, Water, the Petro-chemical industry, etc.), which may have buried metallic pipework within the hot zone should be advised so that precautions can be taken by their staff when working on the metalwork within the zone. Again, there may be financial costs involved for additional protective measures.
- (iii) Special precautions must be taken with the earthing arrangements at any 11kV substation situated within the zone.

Where there is equipment belonging to other authorities within the hot zone area, then a number of methods may be adopted to reduce the risk of damage or danger. This includes physical diversion, addition of insulation, adoption of new protection schemes and new safe procedures. The costs associated with this will be subject to negotiation, in particular the “first comer” agreement with BT.

1.2 Explanation of E.R. S.36 ‘Procedure to Identify and Record Hot Substations’

In 1988, the Electricity Association issued Engineering Recommendation S.36 entitled “Procedure to Identify and Record Hot Substations”. This document was produced after consultation with British Telecom, and it places a requirement on Electricity Companies to notify BT of the location of substations or plant which would be hot under maximum earth fault conditions. This requirement obviously now extends to other affected

Telecommunication Companies. The most important part of the document is acceptance by BT that 33kV lines can be treated as high reliability, meaning that the 650V limit can be used if suitable protective equipment is in place so that an earth fault is cleared within 0.2 seconds. Where schedules did not exist, BT accepted that requests for complete schedules for areas would not be required. Interim 100m zones would be used at sites with severe BT plant implications, in order that costs for protecting their equipment could be calculated. Clearly, there was an understanding that schedules would be progressively completed and that these would be carried out quickly at individual nominated sites where BT needed the information for planned work in the area.

The document also highlights the onerous responsibility on each Electricity Company to ensure that Telecommunication Company staff are protected from excessive rise of earth potential by induction or otherwise.

1.3 How to Establish if a Substation is Hot.

S.36 provides for 3 possible alternatives:-

- (i) Initial Approximate Assessment. This method is only applicable to substations which form part of an all-underground cable network.
- (ii) Carrying out detailed calculations.
- (iii) By measurement.

Note that the assessment needs to include calculations for both an internal fault at the substation at the higher voltage (for example a fault thrower operation) and an external fault at the lower voltages. For example, a remote 11kV cable fault beyond a section of unearthed overhead line. The 650V limit will normally apply for the internal fault and the 430V limit for the external one.

1.4 Establishing the Limits of the Hot Zone.

In the absence of an assessed or measured hot zone, or a locally agreed zone, a zone based upon an area 100m from the substation perimeter electrode (if its position is known) or the perimeter fence (if the electrode system is within the fenced area, but possibly its actual location unknown) and any outgoing cables will be assumed by BT, or other any Telecommunication Company, for an initial appraisal of likely interference with their plant.

If the site is hot, but the calculated hot zone is less than 100m, then the zone would be extended by a 2m corridor either side of outgoing hessian served cables up to 100m from the site boundary. (unless the actual hot zone calculation has taken into account the cable sheaths).

Cables with high sheath insulation are ignored for calculation of the hot zone, but note that these will transfer the potential to the earthing system at their remote end.

1.5 Completion of Schedules and Who to Notify.

Each REC is required to maintain a schedule of Grid and Primary substations, or sites with Generation, with operating voltages of 33kV or greater; which are classified as hot. These schedules must be prepared annually and include future substations when planning permission is applied for.

1.6 Information Required

Having notified BT (or any other Telecommunication Company) that a substation is hot, there is no requirement to provide any further information unless specifically asked to do so. Should such a request be made the following information should be provided.

- (i) Whether 430V or 650V was used to determine if the substation was hot.
- (ii) The maximum present or foreseeable rise of Earth Potential Rise that may be experienced.
- (iii) A plan to scale of not less than 1:2500 showing details of the hot zone and site boundary. This plan should also show the location of any known or buried conductors connected to the main earthing, which can function as part of the main electrode system. These include cables where the metallic sheath/armour is not insulated, that extend for a distance up to 100m beyond the site boundary fence, or up to the extremity of the hot zone, whichever is the greater. Note that computer prediction or measurement of the hot zone will usually show that the hot zone occupies a smaller area than 100m or that calculated using the formula in EATS 41-24.

1.7 Responsibility for Costs of Remedial Action

Statute Law lays down onerous requirements on electricity companies relating to the protection of telecommunications operator's equipment.

Telecommunications operators are aware of the protection afforded to telecommunication plant by law (originating with the 1899 Electricity Lighting Clauses Act), particularly when they are the 'second comer'. It is important that all reasonable precautions are taken to avoid interfering with their equipment.

Under the Second Comer Agreement between the Postmaster General and the Electricity Commissioners dated 1928, the 'second comer' should be responsible for costs. In application, therefore, the responsibility for expenditure by either party for any work needed to protect licensed telecommunications operators and their subscribers' equipment rests initially with the 'second comer'. Where the 'second comer' cannot readily be agreed, then the procedure for arbitration given in Engineering Recommendation G60/1 should be applied.

However in the event of licensed telecommunications operators becoming the 'second comer' or a situation arising where the hot zone extends further than 100m from the substation fence, then liability for costs shall be considered in two parts:

- (a) Up to the appropriate 100m zone, the responsibility for costs will rest with the 'second comer'
- (b) Beyond the 100m zone, the responsibility for costs will be agreed locally.

In disputed situations, the cost of any special work carried out by the REC to reduce both the level and the spread of substation rise of earth potential under earth fault conditions shall be recognised as contributing to the necessary protection

Section E11

Earthing Maintenance

33/11kV Distribution Specification

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1. GENERAL

This specification details the timing and extent of the inspection and maintenance required for 11kV plant items.

Maintenance of earthing systems falls into two distinct categories. These are:-

- | | |
|--------------------------------|--|
| Visual inspection. | This shall be carried out as part of the regular substation inspection. The inspector will observe all visible, above ground earth conductors, connections, guards etc., for evidence of corrosion, decay, signs of burning, vandalism or theft. |
| Examination, including testing | This shall be carried out at time of planned routine maintenance. Where necessary this will include periodic excavation to examine buried earth conductor, earth rods, earth plates. |

As part of the examination, testing shall also be carried out. The tests will include -

- Resistance tests across joints using the micro-ohmmeter (Ducter)
- Checking the integrity of the bonding of all normally accessible metalwork (such as the tank of a transformer) to the substation earth or grid.
- Measurement of the substation earth value (to be compared with the design specification) and for substations with segregated earthing, checking the integrity of the segregation.

At many existing locations, it is probable that earthing arrangements do not meet the current standards. Where glaring examples of failure to meet current standards are obvious, they shall be reported.

When carrying out any form of maintenance, it is important to keep adequate records of the results of inspection/examination and testing, so that these may easily be retrieved.

2. MAINTENANCE OF EARTHING AT DISTRIBUTION GROUND MOUNTED SUBSTATIONS

2.1 Inspection

At the normal substation inspection, the inspector should visually check all earthing and bonding electrodes and connectors, particularly noting the condition of any bi-metallic connectors. The inspection should cover whichever of the following items are appropriate; checking particularly whether any electrode or connection are decayed, corroded, otherwise damaged, have been vandalised or is missing:-

- (i) The main HV earth electrode termination. This is normally connected either to the case of a transformer or HV switchgear.
- (ii) The bonding connection between any plant items which are situated adjacent to each other.
- (iii) The LV earth termination, where this terminates at the substation. This is normally connected onto the neutral bar via a disconnecting link at the distribution pillar.
- (iv) The connection to any earth mats which may be installed adjacent to switchgear.
- (v) The bonding connection to metallic fencing.
- (vi) The bonding connection to a metal enclosure

2.2 Ground Mounted Plant Installation Inspection Model Form

Items To Check	Damaged Yes/No	Corroded Yes/No	Missing Yes/No
Main H.V. earth termination			
Bonding connections between plant items			
LV neutral earth termination			
Earth mat connections			
Bonding connections metal enclosure			
Bonding connections to metallic fence			

Inspectors Name	
Date of Inspection	

2.3 Examination

Examination will normally take place as part of routine substation maintenance.

The examination will divide into two parts:-

Inspection. The inspection under examination will cover the same items as listed in 2.1. However, at normal substation inspection, the inspector is only looking for obvious defects.

Under inspection as part of the examination, the inspector should determine whether the conductor or connections are in a good enough state to last until the next examination. Where any real doubt exists, sections of the conductor and/or connections should be remade. The results of the inspection and any remedial work should be fully documented.

Testing and Measurement. • Joints

A resistance measurement should be taken across all exposed accessible joints/connections using a micro-ohmmeter. The value should be compared with the manufacturers recommended value, or with the value measured for other similar joints. Any joint where the resistance value is excessive is required to be broken down cleaned and remade, or replaced.

The remaking or replacing of an existing joint can be a hazardous procedure even if the local plant has been made dead. Fault current can pass through the substation's earthing system from a remote earth fault. Approved procedures must be used.

• Bonding Checks.

The integrity of bonding of each item on site, as listed in 2.1. should be checked using a micro-ohmmeter (Ducter).

• Substation Resistance.

On completion of all other testing the final check to be carried out is the measurement of the substation earth values.

3. MAINTENANCE OF EARTHING AT POLE-MOUNTED DISTRIBUTION SUBSTATIONS AND OTHER POLE-MOUNTED PLANT.

3.1 Inspection

At the normal foot patrol of the overhead line section to which the transformer/switchgear is connected, the inspector should inspect the components on the pole, using binoculars for those items out of range of normal sight. The inspection should cover whichever of the items are appropriate; checking particularly whether any electrode or connections are:- decayed, corroded, otherwise damaged, have been vandalised or is missing.

- (i) The HV earth electrode termination. This should be insulated up to a minimum of 3m above ground level.
- (ii) The LV earth electrode termination, if appropriate. This should be insulated up to a minimum of 3m above ground level and should be run separately from any HV connection.
- (iii) The bonding connection between the HV electrode, the transformer tank (if appropriate) and any other metal-work such as cross-arms, tops of stays etc.
- (iv) The connection to an earth mat which may be required with any hand operated switchgear.

3.2 Examination

Examination of pole-mounted transformers and other pole-mounted plant will take place as two separate items.

Climbing inspection	To carry this out requires the equipment to be placed under Permit to Work. It is not proposed that this is carried out to a set frequency. Opportunity should be taken, whenever there is an outage of a pole-mounted substation for other reasons, to carry out a more detailed inspection than can be carried out from the ground, particularly checking each connector.
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Examination, including testing	Where necessary this will include periodic excavation to examine buried earth conductor, earth rods, earth plates.
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The value of the HV and LV earth electrodes shall be measured and the separation test carried out (where appropriate).

The results of the tests should be recorded, and any remedial action required, carried out.

3.3 Pole Mounted Plant Installation Inspection Model Form

Items To Check	Damaged Yes/No	Corroded Yes/No	Missing Yes/No
Main HV earth termination			
Bonding connections between plant items			
LV neutral earth termination			
Earth mat connections			
Protective earth cover (capping)		N/A	
	YES/NO		
Are earth conductors insulated to a minimum height of 3m ?			

Inspectors Name	
Date of Inspection	

Section E12

Earthing Maintenance

132/33/11 kV Substations

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1. GENERAL

1.1 Maintenance Categories

Maintenance of earthing systems falls into two distinct categories. These are:-

Visual inspection.	This shall be carried out as part of the regular substation inspection. The inspector will observe all visible, above ground, earth conductors, connections, guards etc., for evidence of corrosion, decay, signs of burning, vandalism or theft.
Examination, including testing.	Where necessary this will include periodic excavation to examine buried earth conductor, earth rods, earth plates.

As part of the examination, testing shall also be carried out. The tests will include -

- Resistance tests across joints using the micro-ohmmeter (Ducter)
- Checking the integrity of the bonding of all normally accessible metalwork (such as the tank of a transformer) to the substation earth or grid.

Measurement of the substation earth value (to be compared with the design specification) and for substations with segregated earthing, checking the integrity of the segregation.

At many existing locations, it is probable that earthing arrangements do not meet the current standards. Where glaring examples of failure to meet current standards are obvious, they shall be reported.

When carrying out any form of maintenance, it is important to keep adequate records of the results of inspection/examination and testing, so that these may easily be retrieved.

1.2 Inspection 132/33/11kV

At the normal substation inspections, the inspector should check all earthing connections especially any bi-metallic connections, visually for the following items shown on the inspection form in section 1.2, reporting where any connection appear to be damaged, decayed, missing or vandalised.

1.3 132/33/11kV Substation Inspection Model Form

Connections		Damaged Yes/No	Corroded Yes/No	Missing Yes/No
Overhead metal tower situated within the substation boundary				
Fault thrower				
Surge Diverters				
Capacitor voltage transformers				
Transformers and reactors				
Neutral earthing resistors				
Other ground mounted plant & structures				
Above ground cable connections				
Metallic Fence	Yes /No	Damaged Yes/No	Corroded Yes/No	Missing Yes/No
Visibly connected to earth				
Visible bond across gates				
Electrode installed below crossing overhead lines				
Has separation between fence & earth grid or plant items been visibly compromised		n/a	n/a	n/a
Are internal fences or external third party fences connected to the fence		n/a	n/a	n/a
General Items	Yes /No			
Are weeds growing through gravel				
Have the insulating properties of the gravel been compromised				

Inspector's Name	
Date of Inspection	

1.4 Examination 132/33/11kV

- (i) Examination will consist of three separate but related parts. These are:-
- To select portions of the buried electrode system, for examination via small trial holes.
 - To carry out a more thorough inspection of all items listed in section 1.2
- and
- To carry out specific testing and measurement of the earthing installation.
- (ii) Selected Excavation and Examination

As a pre-requisite to carrying out a detailed examination, the substation records should be studied to confirm the existing layout. It is recommended that this layout be checked by carrying out a survey from ground level, to trace the electrodes.

If the survey reveals that there is a significant difference between the drawing and actual, further investigation and excavation may be necessary before updating the drawing.

Since the greatest proportion of the earth electrode system is buried, it is obviously impracticable to carry out a detailed examination of the system. However, neither is it reasonable to assume that the electrode system, once buried, will remain in good condition forever.

It is therefore required that prior to commencement of detailed examination, a small, representative, sample of location be chosen to excavate and expose the electrode, particularly at a point of below-ground connection. Several connections from above ground plant should be uncovered back to their connection to the buried earth tape/grid, to check condition through various soil layer materials.

When carrying out excavation, the soil should be tested for pH. value. This should lie between 6.0 and 10.0. For soil outside these limits, it is probable that corrosion of the copper conductors/connectors will be evident. At some locations, it is believed that it was the practice to use waste power station ash as a bedding for earth electrodes. This is known to be acidic and is likely to cause corrosion on the conductors. At any locations where tests show the pH. value of the soil to be outside these limits consideration shall be given to replacement of the soil and/or electrode system.

Should the examination of any exposed conductor or connection give cause for concern, then additional excavations should be carried out at other selected points on the site.

Warning: Note that corroded conductor is not to be interfered with or broken. This may introduce potential differences and an electric shock risk.

1.4.1 Detailed Inspection as part of Examination

At the normal substation inspection, the substation inspector is required to check and report on the earth conductors and connections that are visible without removing covers or lifting trench covers etc.

During the detailed examination, an inspection should be carried out on all the items listed under section 1.3, but where practicable, covers should be removed, cable trench lids lifted etc., to enable a more thorough inspection to be carried out.

The results of all inspections must be fully documented.

1.4.2 Testing and Measurement

- **Joints.**

A resistance measurement should be taken across all exposed accessible joints/connections using a micro-ohmmeter. The value should be compared with the value recommended by the manufacturer and with the value measured for other similar joints. Any joint where the resistance value is excessive will require to be either broken down, cleaned and remade, or in the case of a compression joint replaced.

Warning: The remaking or replacing of an existing joint can be a hazardous procedure even if the local plant has been made dead. Fault current can pass through the substation's earthing system from a remote earth fault. Approved procedures must be used.

- **Bonding Checks.**

The integrity of the bonding of each item on site, as listed in Section 1.2, should be checked using a micro-ohmmeter.

- **Overall Substation Earth Impedance.**

Where possible, on completion of all other testing, a measurement of the overall substation earth electrode value is to be carried out.

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