

## **Company Directive**

### **ENGINEERING SPECIFICATION EE SPEC : 89/2**

#### **Relating to Fixed Earthing Systems for Major Substations**

##### **Summary**

This document specifies requirements for design, installation and commissioning of fixed earthing systems at major substations. It is intended for use as part of Invitations to Tender or for schemes involving Competition in Connections or for connections where the customer site will be designed to accommodate WPD  $\geq 33\text{kV}$  intake equipment. It does not replace ST:TP21B which is for internal WPD use and contains guidance on the application of the above requirements.

**Author:** Simon Scarbro

**Implementation Date:** November 2012

**Approved by**



**Policy Manager**

**Date:**

21 December 2012

**All references to Western Power Distribution or WPD must be read as National Grid Electricity Distribution or NGED**

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<b>Document Revision &amp; Review Table</b>		
<b>Date</b>	<b>Comments</b>	<b>Author</b>
<b>22/11/12</b>	<b>Minor amendments to pages 3, 4, 11, 12, 17 &amp; 18, all of which are self-explanatory.</b>	<b>S. Scarbro</b>
<b>20/12/12</b>	<b>Commissioning tests are now defined in section 9.0.</b>	<b>S. Scarbro</b>

## 1.0 INTRODUCTION

- 1.1 This document specifies requirements for design, installation and commissioning of fixed earthing systems at major substations.
- 1.2 Guidance relating to the application of this Specification to designs involving 33kV Competition in Connections is provided in 'Outline Design Guide for Customers Seeking WPD Adoption of Indoor 33kV Switchgear and Associated Equipment Housings', available on request.

## 2.0 SCOPE

- 2.1 This document is intended for use as part of Invitations to Tender or for schemes involving Competition in Connections or for connections where the customer site will be designed to accommodate WPD  $\geq 33\text{kV}$  intake equipment. It does not replace ST:TP21B which is for internal WPD use and, whilst meeting the requirements set out in this document, provides additional guidance on the application of these requirements.

## 3.0 COMPLIANCE WITH STANDARDS

- 3.1 This document makes reference to or implies reference to the following documents and it is important that users of all standards and Technical Specifications ensure that they are in possession of the latest issues together with any amendments. **Design and installation shall comply with the listed standards unless otherwise specified to the contrary. EA TS 41-24 shall take precedence over BS 7354 and BS 7430.**
- 3.2 **Standards**
- 3.3 Whilst the IEC base document is listed for information, the prime document which shall take priority is the British Standard enacting the European Standard (EN) or European Harmonisation Document (HD).

British Standard	EN/HD/ISO Reference	Title	IEC/ISO Base
BS 7354	EN 60298	Design of High Voltage Open Terminal Substations	IEC 298  IEC 60724  IEC 60479-1
BS 7430		Code of Practice for Earthing	
BS 1432		Specification for copper for electrical purposes: high conductivity copper rectangular conductors with drawn or rolled edges	
BS 6360		Specification for conductors in insulated cables and cords	
BS 4109		Specification for copper for electrical purposes: Wire for general electrical purposes and for insulated cables and flexible cords	
BS 2898		Specification for wrought aluminium and aluminium alloys for electrical purposes. Bars, extruded round tube and sections	
BS 1377-3		Methods of test for soils for civil engineering purposes. Chemical and electro-chemical tests	
BS EN13043		Aggregates for use in bituminous mixtures and surface treatments for roads, airfields and other trafficked areas	
BS EN60298		A.C. metal-enclosed switchgear and controlgear for rated voltages above 1kV and up to and including 52kV.	
		Guide to the short-circuit temperature limits of electric cables with a rated voltage not exceeding 0.1/1.0kV	
	Effects of current on human beings and livestock. Part 1: General aspects		

### 3.4

#### ENA Technical Specifications and Engineering Recommendations

Technical Specification	Title
EA TS 41-24	Guidelines for the Design, Installation, Testing and Maintenance of Main Earthing Systems in Substations
EA TS 43-94	Earth Rods and the Connectors
EA ER S34	A Guide for Assessing the Rise of Earth Potential at Substation Sites
EA ER S36	Identification and Recording of 'Hot Sites' – Joint Electricity Industry/British Telecom Procedure

## 4.0 DEFINITIONS

CCITT	International Telegraph and Telephone Consultative Committee.
CDEGS	A software package permitting the investigation of earthing problems.
EARTH ELECTRODE	A conductor or group of conductors in intimate contact with, and providing an electrical connection to, earth.
EARTH IMPEDANCE	The impedance between the earthing system and remote reference earth.
EARTH POTENTIAL	The difference in potential which may exist between a point on the ground and remote reference earth.
EARTH RESISTANCE	The resistance of the earth between the earth electrode and remote reference earth.
EARTHING CONDUCTOR	Conductor which connects plant and equipment to the earth electrode.
EARTHING SYSTEM	The complete interconnected assembly of earthing conductors and earth electrodes (including cables with uninsulated sheaths).
HOT SITE	A substation where the rise of earth potential exceeds the appropriate CCITT level. The CCITT level is 430V RMS unless the power circuits contributing to the earth fault currents are high reliability type, having an operating voltage of 33kV or greater and controlled by switchgear with main protection that will clear both a line or busbar earth fault current within 500ms and generally within 200ms. In this latter case the CCITT level is 650V RMS.
HOT ZONE	The area over which the rise of earth potential may exceed the appropriate CCITT level.
LIVE	Electrically charged.
MALT/MALZ	Modules of CDEGS which permit the analysis of earth electrode arrangements in earth structure models. MALZ is suited to large electrode systems.
RESAP	A module of CDEGS which permits the construction of equivalent earth structure models given soil resistivity data.
STEP VOLTAGE	The part of the earth potential rise due to an earth fault which can be picked up by a person with a step-width of 1m, assuming that the current is flowing via the human body from foot to foot.
TOUCH VOLTAGE	Voltage appearing during an insulation fault, between simultaneously accessible parts; hand-to-foot or hand-to-hand.

## 5.0 GLOSSARY OF SYMBOLS

$I_E$	Total current passing to ground
$I_F$	Total earth fault current
$I_{ES}$	Component of $I_E$ passing to ground through mesh electrode
$I_{SR}$	Current returning through earthwire or cable sheath
$R_{ES}$	Grid electrode earth resistance
$Z_E$	Substation earth impedance
$U_E$	Rise of earth potential of substation relative to remote reference earth
$U_{touch}$	Touch voltage
$U_{step}$	Step voltage

## 6.0 FUNDAMENTAL REQUIREMENTS

### 6.1 Design Requirements

#### 6.1.1 Earthing systems shall be designed to:

- a) Comply with the Electricity Quality and Continuity Regulations
- b) Comply with EA TS 41-24, as modified by Company Policy
- c) Control the risk of human electric shock
- d) Permit the flow of sufficient earth fault current for satisfactory operation of System Protection
- e) Permit the flow of earth fault current without exceeding electrical, thermal and mechanical limits
- f) Permit correct operation of lightning protection
- g) Minimise earth potential rise to avoid 'hot site' classification where reasonably practicable
- h) Minimise the extent of the 'hot zone' so far as reasonably practicable
- i) Avoid voltage rise above equipment withstand levels (i.e. 3kV)
- j) Minimise lifetime ownership costs
- k) Perform the above functions through its expected lifetime.

6.1.2 The risk of electric shock shall be controlled by use of voltage limits derived from the C1 current-time curve of IEC 60479-1.

6.1.3 The short-time current rating of earthing system components that may carry fault current shall be consistent with the *specified* rating of the plant (e.g. as *specified* in the Invitation to Tender) and current division. Back-up protection operation shall be assumed with an operating time of 3s.

6.1.4 The thermal rating of earth electrode shall be in excess of the current-time curve defined by protective devices.

6.1.5 Earthing system components that are not required to carry earth fault current (intentional or otherwise) shall be sized according to mechanical and corrosion performance considerations.

6.1.6 Lifetime ownership cost considerations shall include purchase cost, corrosion performance and theft deterrence.

## 6.2 **Installation Requirements**

6.2.1 Earthing systems shall be installed such that the design requirements are met. The method of installation shall:

- a) Employ safe systems of work, controlling the risk of electric shock and applying WPD's Distribution Safety Rules
- b) Avoid damage to/from other works (e.g. drains, cables etc)
- c) Maximise the lifetime by suitable measures where hostile soil conditions exist.

## 6.3 **Commissioning Requirements**

6.3.1 Post-installation commissioning tests shall be performed to verify compliance with the design requirements. Safe systems of work shall be employed.

## 7.0 **DESIGN**

### 7.1 **Soil Model**

7.1.1 Perform soil resistivity measurements at two representative locations near the substation using the Wenner test method and appropriate probe spacings (i.e. 1m, 1.5m, 2m, 3m, 4.5m, 6m, 9m, 13.5m, 27m, 36m and 54m).

7.1.2 Analyse the soil resistivity data, taking account of available geotechnical data, using CDEGS RESAP software (full, unrestricted version) and determine a representative multi-layer soil model.

### 7.2 **Substation Earthing System Layout**

7.2.1 The substation earthing system layout shall be based upon the following but modified as necessary to meet the fundamental requirements:

- a) Comprise a perimeter ring of electrode with interconnections forming a mesh/grid.
- b) Enclose the area containing all exposed conductive parts that may become LIVE during an earth fault.
- c) Have a maximum spacing between parallel mesh electrode of 10m at the outer edges of the mesh and 12m in the inner area. Actual mesh size and electrode position shall be determined by electric shock considerations.
- d) Provide duplicate 'independent' connections to the mesh where connections are critical (e.g. transformer neutrals, phase-earth fault throwers, overhead line terminal towers, indoor switchgear earth bars).
- e) Where reasonably practicable, have vertical earth rods at the corners of the mesh, minimum 3m length.
- f) Achieve EITHER 2m separation from the compound fence (substation earth electrode within fence and fence separately earthed) allowing for the swing arc of metal gates and doors OR encompass the fence with multiple connections to it. The separately earthed fence is the preferred method.
- g) Be at a depth of 0.6m.
- h) Connect to piling.

- i) Where necessary for touch voltage control, connect to building floor steel reinforcing (e.g. control room base) with a parallel loop of earth electrode under the plinth.
- j) Have the fence earthed at corners and additional points where crossed by overhead conductors and not less than every 50m.
- k) Have gateposts bonded together and gates bonded to gateposts.

7.2.2 Special arrangements are required for substations containing G.I.S switchgear due primarily to high-frequency switching transients. Special arrangements are also required for substations containing air-cored reactors due to the possibility of induced currents from strong localised magnetic fields.

### 7.3 **Substation Mesh Earth Electrode Resistance, $R_{ES}$**

7.3.1 The resistance,  $R_{ES}$ , of the substation mesh earth electrode arrangement in the soil model shall be determined. This shall be performed using CDEGS MALT/MALZ software, whichever is more appropriate. NB MALZ is necessary for large electrode systems (e.g. wind farms).

### 7.4 **Substation Earth Impedance, $Z_E$**

7.4.1 The chain impedance of overhead towers and impedance of external horizontal electrode shall be determined using ER S34 or equivalent. The substation earth impedance,  $Z_E$ , shall be determined from the sum of the parallel impedances.

### 7.5 **System Protection Clearance Time**

7.5.1 The total time to clear each relevant earth fault on the WPD system for use in touch and step voltage assessment shall be provided by WPD.

### 7.6 **Earth Potential Rise**

7.6.1 The current flowing into  $Z_E$ ,  $I_E$ , shall be determined from the total fault current,  $I_F$ , by allowing for current returning via other (non- $Z_E$ ) paths:

- a) Current returning by local transformer neutrals,  $I_L$ , shall be determined by WPD
- b) Current returning via earth wire or cable sheath,  $I_{SR}$ , shall be determined from ER S34 or equivalent.

7.6.2 No allowance for fault arc impedance shall be made.

7.6.3 The earth potential rise (EPR),  $U_E = I_E \times Z_E = I_{ES} \times R_{ES}$ , shall be determined for the internal and external fault conditions.

### 7.7 **Touch and Step Voltage Limits**

7.7.1 EATS 41-24 defines touch and step voltage limits by fault clearance time. The appropriate limits shall be determined for the internal and external fault conditions assuming correct protection operation.

## 7.8 Assessment of Touch and Step Voltages

7.8.1 The earth electrode layout shall be analysed in the soil model using CDEGS MALT/MALZ software, whichever is more appropriate. The worst-case touch and step voltages across the substation, internal and external to the compound fence, including nearby buildings, shall be determined.

7.8.2 Compliance with the touch and step limits shall be checked, taking account of any effective high resistivity ground surface covering (i.e. aggregate, tarmacadam etc). For a ground surface covering to be considered effective it shall meet the requirements of Table F1 in Appendix F. The electrode layout shall be adjusted as necessary to achieve touch and step voltage compliance taking account of all the fundamental design requirements.

7.8.3 Reducing the depth of the earth electrode reduces touch potential and increases step potential. A minimum depth of 0.5m applies to conductors included in  $R_{ES}$  to minimise variation should surface soil freeze.

## 7.9 Connectivity and Detailed Earthing Layout

7.9.1 The detailed design shall include connection of the following to the substation earth electrode mesh via two independent routes:

- a) Devices as necessary to provide System Earth(s) including neutral terminals of power transformers, neutral earthing devices (i.e. liquid earthing resistors or neutral earthing reactors) or earthing transformers.
- b) Earthing conductor from earth terminals of phase-to-earth fault throwers
- c) Overhead line terminal towers, where continuity is not provided by cable sheath/armour
- d) Indoor switchgear earth bar.

7.9.2 The design shall include connection of the following to the substation earth electrode:

- a) Earth switch terminals
- b) Cable sheath/armour, subject to special requirements covered below
- c) HV steelwork
- d) Earth mats
- e) Ancillary metalwork (accessible)
- f) Structural earth electrode (i.e. control room floor steel reinforcing) where necessary for touch voltage control.

7.9.3 Note, where frame-leakage busbar protection is present, the bonding shall not circumvent the associated current transformers.

7.9.4 Above ground exposed conductive parts that can attain different potentials and would present a hand-to-hand touch hazard shall be either:

- a) Effectively bonded together, or
- b) Effectively shrouded/insulated, or
- c) Physically separated to control the hazard. A 2m separation shall be taken to give effective separation.

- 7.9.5 Note that it is important not to compromise the design (e.g. avoid connection of earth mesh to metalwork outside of the interconnected mesh or connection to the fence if this is intentionally separate etc).
- 7.9.6 Stance earth mats shall be provided to control touch potential for metalwork which is not fully integral with the main equipment:
- a) Air-break switch disconnecter handles
  - b) Earth switch handles
  - c) Fault thrower handles.
- 7.9.7 The earth mat design shall ensure control of touch potential for all operator positions.
- 7.9.8 The earth mat shall be connected direct to the handle with a spur connection to the substation earth mesh electrode below ground level.
- 7.9.9 See below for cable sheath earthing and for fence and gate requirements.
- 7.10 **Choice of Materials**
- 7.10.1 Only Approved Materials shall be used to construct the formal substation earthing system. These are given in Appendix A by standard and role. Other materials may be offered for consideration for approval.
- 7.10.2 Aluminium shall not be used below ground level or within 150mm of it.
- 7.11 **Selection of Earthing System Component Size**
- 7.11.1 Appropriate size for each part of the earthing system depends on function:
- a) Earthing conductor that may carry fault current to the earth electrode
  - b) Bonding conductor that is not reasonably likely to carry fault current
  - c) Earth electrode.
- 7.12 **Earthing Conductor**
- 7.12.1 Earthing conductor that may carry fault current intentionally (e.g. connection to transformer neutral or phase-earth fault thrower) or following insulation breakdown or other failure (e.g. fallen conductor) shall have a short-time current rating consistent with Clause 6.1.3. For switchgear the requirements for earthing of the enclosure set out in BS EN 60298, clause 5.3.1 shall also be met, subject to the minimum conductor size requirements in 7.12.8 below.
- 7.12.2 Where, through switching the System Earth, connection can be made solid rather than through a neutral earthing device, earthing conductor ratings shall take account of this possible operational arrangement.
- 7.12.3 For 'critical' connections that are duplicated (e.g. connections to transformer neutrals etc) each connection shall be fully rated.

- 7.12.4 The short-time ratings of earthing conductor shall be assessed using the formula in IEC 60724. Appendix B gives the formula and assumptions that shall apply regarding material constants and permissible temperature rise. Appendix C details calculated short-time ratings for standard conductor sizes.
- 7.12.5 Consideration shall be given to faults fed from one system voltage into that of another system voltage (e.g. 132kV conductor dropping onto 33kV equipment if physically possible).
- 7.12.6 For simplicity, selected standard sizes are given by substation type in Table 1 below. Note that these assume all joints are welded or brazed and shall be checked against the requirements above.
- 7.12.7 Table C4 in Appendix C gives copper equivalent sizes in other materials.

Nominal Voltage (kV)	3s Fault Rating	Required cross-sectional area in copper	Standard size in copper
132/66	25kA (3-phase or single-phase, whichever higher)	200 mm <sup>2</sup>	50mm x 4mm strip
132/66	31.5kA (3-phase or single-phase, whichever higher)	260 mm <sup>2</sup>	50mm x 6mm strip
132/66	40kA (3-phase or single-phase, whichever higher)	330 mm <sup>2</sup>	75mm x 6mm strip
33	16kA (3-phase or single-phase, whichever higher)	130 mm <sup>2</sup>	50mm x 3mm strip
33	20kA (3-phase or single-phase, whichever higher)	160 mm <sup>2</sup>	50mm x 4mm strip
33	25kA (3-phase or single-phase, whichever higher)	200 mm <sup>2</sup>	50mm x 4mm strip
11	12.5kA (3-phase or single-phase, whichever higher)	100mm <sup>2</sup>	25mm x 4mm strip or 100mm <sup>2</sup> stranded
11	16kA (3-phase or single-phase, whichever higher)	130 mm <sup>2</sup>	50mm x 3mm strip or 150mm <sup>2</sup> stranded
11	20kA (3-phase or single-phase, whichever higher)	160 mm <sup>2</sup>	50mm x 4mm strip

**Table 1 - Standard earthing conductor sizes by substation nominal voltage and fault rating**

- 7.12.8 Where the required short-time current rating implies a cross-sectional area less than 70mm<sup>2</sup> copper-equivalent (ce), a minimum of 70mm<sup>2</sup> ce shall apply. The minimum permissible thickness of copper and aluminium strip shall be 3mm and 4mm, respectively. For stranded copper conductor the minimum strand diameter shall be 3mm.
- 7.12.9 Fence earthing conductor, connecting the fence to its earth electrode, shall be a minimum of 70mm<sup>2</sup> ce.

7.12.10 Earthing conductor used to connect to earth mats shall have a rating equivalent to the associated HV steelwork earthing conductor.

### 7.13 Use of Steel Support Structure as Earthing Conductor

7.13.1 To minimise conductor theft, it is preferred that, where suitable, the steel support structure is utilized as a conductor, replacing copper/aluminium earthing conductor for part of the earthing conductor path. See Standard Substation Construction drawing numbers XP1062 and XP1063. The steel support structure shall not be used to replace copper/aluminium earthing conductor for earth connections to earth switches or fault throwers and nor for connections to surge arresters or capacitor voltage transformers.

### 7.14 Bonding Conductor

7.14.1 Bonding conductor that is not reasonably likely to carry fault current shall be a minimum of 50mm<sup>2</sup> ce (e.g. inter-gatepost bond, hand-rail bond, metal lamp-post or security post bond. However, for bonds which may be subject to movement (i.e. gate-gatepost bonds and metal trench cover bonds) a minimum of 35mm<sup>2</sup> ce shall apply. The minimum permissible thickness of copper and aluminium strip shall be 3mm and 4mm, respectively. For stranded copper conductor the minimum strand diameter shall be 3mm.

### 7.15 Earth Electrode

7.15.1 Each section of the interconnected earth mesh shall have a short-time current rating:

- a) No less than 60% of the earthing conductor rating given above
- b) Equal to the earthing conductor rating given above where it connects single-phase switchgear together.

7.15.2 Spur connections shall be fully rated where they connect to above ground earthing conductor. In other cases, the spur connections shall be rated according to the distribution of fault current.

7.15.3 In addition to the above, earth electrode shall be a minimum of 70mm<sup>2</sup> ce and, where applicable, the minimum permissible thickness of copper strip shall be 3mm. For stranded copper conductor the minimum strand diameter shall be 3mm.

7.15.4 Table 2 defines minimum sizes of driven earth rod.

Type of Earth Rod	Minimum Nominal Diameter
Solid copper rod	15.0mm
Copper-clad steel	12.5mm

**Table 2 - Minimum driven earth rod size**

7.15.5 To avoid excessive temperature rise at the surface of the earth electrode it is necessary to provide sufficient surface area in contact with the soil. The total surface area of the buried bare earth electrode system shall be determined. The adequacy of this value shall be checked using the formula in EA TS 41-24 assuming a three second fault. Appendix D gives the formula.

## 7.16 **Additional Issues**

### 7.16.1 **Power Cable Sheath Earthing**

7.16.1.1 Three-core power cables shall have their sheaths and armouring earthed at each end. Depending on the earth fault current that can flow in the cable sheaths it may be necessary to interconnect the ends with separate earth electrode.

7.16.1.2 Single-core cables require special consideration as load-related circulating current may cause significant de-rating. Each installation shall be individually assessed. Precautions shall be taken to control induced touch voltage to not exceed 50V.

7.16.1.3 Care is required with the routing of sheath earthing with respect to current transformers to avoid protection maloperation by through fault current or capacitive current.

### 7.16.2 **Multicore Sheath, Pilot Cable Sheath and Gas/Oil Pressure Alarm Earthing**

7.16.2.1 Multicore cable sheaths entirely within the substation shall generally be earthed at each end by connection to the substation earthing system. If it is necessary to single-point earth multicore cable sheaths, precautions shall be taken to control induced touch voltage to not exceed 50V.

7.16.2.2 Pilot cable sheaths and gas/oil pressure alarms from remote external cables require special consideration and each installation shall be individually assessed.

### 7.16.3 **Fences and Gates**

7.16.3.1 Substation compound fences and gates shall be effectively earthed.

7.16.3.2 To control hand-to-hand touch hazards between exposed conductive parts that can attain different potentials, two mutually exclusive arrangements for the substation compound fence are permitted:

- a) Independently earthed fence with minimum 2m separation from substation earth electrode and effective separation from all plant connected to it, including power cables with conducting sheaths.
- b) Fence earthed via substation earth electrode.

7.16.3.3 Consideration shall be given to the touch voltage on the fence. Where necessary, a perimeter potential grading electrode shall be provided.

7.16.3.4 Gates in substation compound fences shall be connected together via their gateposts.

7.16.3.5 Metal fences which abut the substation compound fence shall be effectively separated either by:

- a) 2m physical separation, or
- b) Effective shrouding/insulation.

#### 7.16.4 **Stays**

7.16.4.1 Care is required with the positioning of overhead line stay wires relative to the substation compound fence and substation earthing system. The following arrangements are permitted:

- a) Stay within the substation earth mesh and connected to it.
- b) Stay effectively separated by 2m above and below ground from equipment that can attain a different potential. With this arrangement insulation of the stay from the pole steelwork earth is required to reduce possible touch voltage if the steelwork is earthed via the substation earthing system. The Electricity Safety, Quality and Continuity Regulations define requirements for stay insulators (minimum height of 3m). Furthermore, it may be necessary to add a potential grading electrode around the stay with connection to the stay to control touch voltage. In this case, the separation requirements shall still apply. The method of installation must take account of mechanical forces acting on the stay and associated ground.

7.16.4.2 Note that failure to insulate the stay from the pole steelwork may cause the steel stay to corrode at an accelerated rate.

7.16.4.3 Overhead line stays shall not be installed such that they compromise the independent earthing of a fence from a substation earthing system.

#### 7.16.5 **Surge Arrestors and Capacitor Voltage Transformers**

7.16.5.1 The earthing associated with surge arrestors and capacitor voltage transformers shall provide effective high-frequency and power-frequency earthing.

7.16.5.2 Where the two functions (i.e. high-frequency earthing and power-frequency earthing) are nominally performed by separate conductors care shall be taken to ensure that the power-frequency current flowing in the 'high-frequency' path does not exceed its power-frequency rating.

#### 7.16.5.3 **Surge Arrestors**

7.16.5.3.1 The power-frequency earthing shall be so arranged and supplemented to also perform as an effective high-frequency earthing system.

7.16.5.3.2 The following general requirements shall apply.

#### 7.16.5.4 **Arrestor Position**

7.16.5.4.1 To maximise the benefit from the surge arrestors:

- a) Position surge arrestors as close as practicable to the protected equipment (e.g. transformer bushing, ideally mounted on the transformer turrets).
- b) Minimise connection lead length to minimise the 'inductive' loop length.

#### 7.16.5.5 Above-ground Earthing Conductor

##### 7.16.5.5.1 Minimise impedance and, in particular, inductance of the above ground earthing conductor:

- a) Ensure there are no 'sharp bends'. Where practicable use a minimum bend radius of 20cm.
- b) Avoid 'loops' where possible. If loops cannot be avoided (e.g. bund walls for transformer surge arrestors), avoid loop length more than eight times the width of the loop open end (as flashover is possible). Minimise loop length relative to the width of the open end.
- c) Avoid changes in conductor direction.
- d) Avoid unnecessary length. Route conductor to earth electrode directly. Ensure buried earth electrode established at closest practicable point (e.g. just outside bund for transformer surge arrestors).
- e) Use multiple paths where practicable (e.g. for transformer turret-mounted surge arrestors ideally four but no less than two across the transformer plinth to the buried earth electrode system).
- f) For turret-mounted arrestors, a dedicated connection from the base of the surge arrestor to the transformer tank is required. Ideally, this would be to a dedicated earth tab, but where this is not possible a suitable bolt or drilled hole shall be used taking care not to impair the transformer tank integrity. The connection shall be below the level of transformer lid gasket to ensure the most direct current path.
- g) For turret-mounted arrestors, although the transformer tank provides a large cross-sectional area for the path of surge current, it is considered that it is not immediately obvious to personnel what the effect of disconnecting the lower transformer tank connection(s) would be upon surge arrestor performance. Given this, a dedicated connection shall be provided that is electrically in parallel with the transformer tank as part of the surge current path.

#### 7.16.5.6 Below-ground Earth Electrode

##### 7.16.5.6.1 Minimise the high-frequency impedance of buried earth electrode at the point(s) where surge current would enter:

- a) Create an electrode arrangement that 'fills' the volume of soil, a hemisphere, around the surge current injection point(s) by installing vertical rod (ideally 6m) and horizontal electrode to approach a 'radial star' arrangement. As a minimum, install the 'radial star' arrangement at the surge current injection point nearest to the surge arrestor(s).
- b) Increase mesh 'density' in the horizontal plane to further fill the effective volume, up to a radius of 20-50m. Spacing between parallel mesh electrodes of the mesh shall be on an 'exponential' basis with highest mesh density closest to the rod (e.g. spacings between parallel electrodes of 0.6m, 1.6m, 4.4m within a 12m mesh square).

- i. Note: electrode further than about 20-50m, measured from the surge injection point along the electrode, has little effect on reducing the high-frequency impedance. Horizontal electrode is generally cheaper to install than deep-driven vertical rods.
- c) Integrate the above into the substation power frequency earthing system.

## 7.16.6 Capacitor Voltage Transformers

7.16.6.1 As a capacitor voltage transformer acts as a short-circuit to earth at high frequencies, it shall have an effective high-frequency earth as well as power frequency earth. The approach detailed for surge arrestors shall be used with the following amendments:

- a) Rod length shall be a minimum of 2.4m.
- b) No increased earth electrode mesh density is necessary.

7.16.6.2 Note that if protection signalling through the capacitor voltage transformer is employed then care is required as carrier equipment may be relatively remote. Specialist advice shall be sought.

## 7.17 Design Deliverables

7.17.1 The following shall be provided to WPD prior to installation:

- a) Drawing showing earthing design and including electrode layout, depth and materials, including sizes.
- b) Design report
- c) CDEGS input files in electronic format on CDROM

7.17.2 The design report shall include:

- a) Soil model and field test results
- b) Substation mesh earth electrode resistance,  $R_{ES}$
- c) Substation earth impedance,  $Z_E$ , and constituent parts (e.g. tower chain impedance etc)
- d) Earth potential rise,  $U_E$
- e) Hot or cold classification
- f) Hot zone contour (ie 430V/650V) plot and 1150V/1700V contour plot, where applicable, superimposed on OS geographical plan
- g) Plots of touch and step voltages (plan view) superimposed on grid electrode
- h) Confirmation that touch and step limits are not exceeded both internally and externally.

7.17.3 Post-installation earth test(s) shall be performed to verify the design has been achieved. Interpretation shall be via CDEGS, MALT/MALZ software, whichever is more appropriate. Where the measurements indicate the design objectives have not been met then remedial action shall be taken.

## **8.0 INSTALLATION PROCESS**

### **8.1 Safety**

8.1.1 To minimise the risk of electric shock it is necessary to control the hazards presented by:

- a) 'Touch', 'step' and 'transfer' potential.
- b) Failure of insulation
- c) Current flowing in earthing systems
- d) Induced voltage
- e) Electrostatically-induced current.

8.1.2 Safe working methods shall be used. In addition to the normal requirements for safe working, appropriate control measures may include:

- a) Using suitable insulated gloves and safety footwear
- b) Using temporary earth mat over a rubber mat at work position
- c) Verifying insulator integrity by visual inspection prior to contact with earthing system
- d) Ensuring compound fencing remains earthed
- e) Temporary adequately rated cross-bonding when making/breaking connections in earthing systems
- f) Insulation to prevent simultaneous contact across earth zones (e.g. insulated isolating links).

### **8.2 Separation From Power Cables And Multicores**

8.2.1 Damage to power cables and multicore cables due to high voltage transients or thermal effects of earth fault current on/in earth electrode shall be prevented by adequate separation. In the absence of other information, it shall be assumed that 150mm separation meets this requirement.

8.2.2 Where separation is not practical, suitable protection shall be applied. To achieve this a suitable covering shall be applied. The length of covering shall be minimised and shall be such that it does not compromise the earthing design.

### **8.3 Joints**

8.3.1 Where reasonably practicable brazed or exothermically welded joints shall be used in major substations for joints in the formal earthing system which may carry fault current (e.g. connections to neutrals, fault throwers, HV steelwork and earth electrode); in cases where the metal support structure forms part of the earthing conductor path (see 7.13.1) the above ground joints to the metal support structure shall be double-bolted. Joints to reinforcing bar shall only be exothermically welded. In all other situations, brazed, exothermically welded, crimped and, when above ground, bolted joints are permitted; in the case of bolted joints, where reasonably practicable, double-bolted joints shall be used. Riveted joints shall not be used. The drilled hole for bolted connections shall not exceed one third of the tape width.

8.3.2 Bolted connections shall not be used below ground.

8.3.3 Precautions shall be taken to prevent corrosion (e.g. bimetallic (dissimilar metals) and chemical).

8.3.4 Inadvertent joints between copper earthing conductor and galvanised steel (e.g. where copper passes earth switch handle support metalwork) shall be avoided or, where this is not possible, the copper at the contact point shall be tinned or, alternatively, greased with a high-temperature copper-based grease (eg ‘Copaslip’ or equivalent).

#### 8.4 **Soil Around Earth Electrode**

8.4.1 Earth electrode shall not be installed direct into highly corrosive soil. Where necessary, non-corrosive soil or other suitable products shall be imported to achieve this requirement - refer to Tables E1 and E2 in Appendix E. In particularly hostile soil, other measures may be required. Soils which shall be considered potentially hostile are given in Table E3 of Appendix E.

8.4.2 Soil around earth electrode shall be free of stones for a radius of 150mm and firmly compacted.

#### 8.5 **Anti-theft Measures**

8.5.1 To prevent theft of the earth electrode by pulling it out of the ground sections of the electrode may be encased in Marconite concrete or low sulphur concrete.

8.5.2 Earthing conductor theft can be discouraged by suitable fixing to structures and use of security-coded paint where required. For security fixing to concrete, stainless steel anchors (i.e. Alcomet FNA II or approved equivalent) shall be used, generally spaced at 300mm centres. For security fixing to steel support structures, M12 x 40 stainless steel countersunk screw, M12 stainless steel round flat washer and M12 stainless steel shear nut shall be used, generally spaced at 300mm centres; holes shall be 14mm diameter, countersunk on rear face; measures shall be taken to prevent corrosion where tape is fixed along its length to structural steelwork – see Standard Substation Construction drawing numbers XP1062 and XP1063.

#### 8.6 **Ground Surface Covering**

8.6.1 To reduce possible body current, high resistivity material shall be applied to the surface in major substations where touch hazards may arise (e.g. open terminal compound, around control building with earthed external metalwork etc). Suitable materials and required thickness are given in Appendix F.

#### 8.7 **Loops for Portable Earths**

8.7.1 Loops shall be provided attached to open-terminal HV steelwork earthing conductor suitable for connection of portable earthing equipment. The cross-sectional area shall not be less than that of the earthing conductor (i.e. they shall be fully rated). The loop length parallel with the support structure shall be 180mm long and 75mm clear of the earthing conductor. For steel support structures see Standard Construction Drawings XP1062 and XP1063; each connection of the loop to the steel support structure shall be a double-bolted connection – suitable corrosion precautions shall be taken (e.g. tinned copper).

## 8.8 **Addition of Metal Plant and Equipment**

8.8.1 The addition of metalwork (e.g. lamp-posts, noise enclosures etc) may cause the design to be compromised such that unsafe touch voltages could arise. Examples include:

- a) Locating metalwork in an area where there is no potential grading (e.g. outside the 'mesh')
- b) Addition of metalwork (e.g. lamp-posts or security posts) outside the earth 'mesh' connecting the fence to the substation earthing system directly or unintentionally (i.e. cable or earth electrode under fence, changing the compound fence position or addition of internal fences)
- c) Addition of metal doors or gates creating hand-to-hand touch hazards between independently earthed fence and metalwork connected to the substation earthing system
- d) Addition of external fences adjacent to earth electrode/compound fence.

8.8.2 Options for controlling the touch voltages include locating the metalwork such that it is a minimum of 1m within the earth 'mesh'. This will not normally cause an unsafe touch hazard unless the design did not control the touch voltage in the particular area concerned.

8.8.3 Where the equipment is to be sited beyond the earth 'mesh', options include:

- a) Ensuring there are no metallic parts exposed (e.g. plastic lighting column). If it has a power supply ensure this is derived from the substation LV AC supply using insulated sheath cable.
- b) Extending the earth mesh to enclose the metalwork with 1m separation around the perimeter. If this compromises an intentional 2m separation with the compound fence move the fence or use insulated panels.

## 8.9 **Multicore Cables**

8.9.1 To prevent double-end earthed multicore cable sheath damage due to passage of earth fault current, earth electrode shall be connected between each end. If possible, the route of the multicore cable shall be made longer than that of the earth electrode connection.

## 8.10 **Cables and Earth Electrode Passing Under Independently Earthed Fencing**

8.10.1 Cables with uninsulated sheaths which pass under independently earthed compound fencing shall be insulated 2m either side to limit the fence potential rise.

## 8.11 **Protection of Communication Circuits at Hot Sites**

8.11.1 Measures shall be applied at hot sites to telecommunication circuits and private pilots to protect equipment, personnel and telecommunication customers. These communication circuits shall be electrically isolated from the substation earthing system. They shall be terminated on appropriate isolating links and isolation equipment. For telecommunication circuits (e.g. BT) the telecommunication operator's requirements shall apply.

- 8.11.2 Isolation equipment shall be capable of withstanding the maximum substation earth potential rise. In the absence of specific requirements, the withstand capability shall be a minimum of 10kV ac RMS at 50Hz for 1 minute. This equipment shall allow the connected apparatus to perform its function adequately.
- 8.11.3 To maintain isolation, the communication cable on the substation side of the isolation equipment shall not run across or with the incoming communication cable.
- 8.11.4 Hot site status and associated hot zone shall be determined together with mitigation requirements.

## 8.12 **Water Services at Hot Sites**

- 8.12.1 New water service pipes into hot substations shall be non-metallic.
- 8.12.2 Metallic water service pipes shall be fitted with insulating insert(s) to prevent transfer of earth potential rise externally to other customers. The insert(s) shall provide a minimum 2m effective separation from the substation earthing system.

## 8.13 **Records**

- 8.13.1 A diagram showing 'as-installed' earthing layout shall be prepared. All subsequent modifications to earthing shall be recorded. The record shall comprise a plan view and shall include:
- a) Earth electrode layout with depths, material, sizes, connectivity and rod position/depth, joint types
  - b) Earthing and bonding conductor layout, material, sizes, connectivity and joint types
  - c) Method of fence/gate earthing and connectivity with substation earthing system
  - d) Special measures (e.g. imported soil, anti-theft measures, insulation under fences, insulating inserts in water services and isolation equipment)
  - e) Details of plant crossing under fences
  - f) Connectivity with towers and earthed poles
  - g) Connectivity with power cable sheaths
  - h) Stay positions
  - i) PVC/PVC insulation
  - j) External earth electrode.
- 8.13.2 A record of the post-installation earth test (required by clause 7.17.3) and its interpretation shall be provided.

## 9.0 **COMMISSIONING**

Commissioning tests shall be performed at appropriate times in the process. These shall include:

- a) Soil resistivity tests using approved earth tester. See 7.1.1 & 7.1.2.
- b) Joint resistance test using approved micro-ohmmeter of each joint in the earthing system.

- c) Bonding test to verify all appropriate metalwork is bonded as per the design. Note bonding tests to terminal towers shall be performed correctly to ST:TP21O, as amended, to control the elevated risk that may arise due to induction.
- d) Earth resistance/impedance test using approved earth tester. See 7.17.3. Note that interpretation by the Slope Method and 61.8% rule are not appropriate for major substations.

ST:TP21O, as amended, defines WPD test method policy.

## APPENDIX A

<b>Material</b>	<b>Standard &amp; Designation</b>	<b>BS EN 13601 Material Designation</b>
Copper – strip	BS 1432 - C101	CW004A
Copper - insulated strip	BS 1432 - C101 & BS 5252	CW004A
Copper - stranded	BS 7884 - C101(C100/C102)	CW004A (CW003A/CW005A)
Copper - insulated stranded	BS 6360	
Copper - rod	EA TS 43-94	
Copper - flexible	BS 6360	
Copper - flexible braid	BS 4109 - C101	CW004A
Copper-clad steel - rod	EA TS 43-94	
Aluminium - strip	BS 2898 - 1350	
Structural Steel NB Not for high-frequency current (e.g. surge arrester or capacitor voltage transformer).	BS EN 485, BS EN 573, BS EN 574, BS EN 755	
Structural Aluminium NB Not for high-frequency current (e.g. surge arrester or capacitor voltage transformer).	BS EN 10025	

**Table A1 - Approved materials by standard and type/grade**

<b>Role</b>	<b>Position</b>	<b>Approved Materials</b>
Earth electrode	Below ground	Copper - strip Copper - stranded conductor Copper-clad steel - rod Copper - rod (where soil classified as 'hostile') Steel piles Steel reinforcing bar
Earthing conductor	Above ground	Copper - strip Copper - stranded conductor Copper-clad steel - stranded conductor Aluminium - strip (not within 150mm of ground level) Aluminium - support structure (subject to adequate cross-sectional area)
Insulated earthing conductor	Above or below ground	Copper - insulated strip Copper - insulated stranded conductor Copper-clad steel - insulated stranded conductor
Gate-gatepost & door bond	Above ground	Copper - flexible or flexible braid

**Table A2 - Approved materials - formal earthing system**

## APPENDIX B

The short-time current rating formula applicable to earthing conductors given in IEC 60724 is:

$$I_c = A \cdot k \sqrt{[\ln[(\theta_f + \beta)/(\theta_i + \beta)]] \cdot 1/t} \text{ where}$$

- $I_c$  = conductor current rating (Amperes)  
 $A$  = conductor cross-sectional area (mm<sup>2</sup>)  
 $k$  = material k-factor (A/mm<sup>2</sup>)  
 $\theta_f$  = final temperature (°C)  
 $\theta_i$  = initial temperature (°C)  
 $\beta$  = material  $\beta$ -factor (°C)  
 $t$  = time (s).

Material	Initial Temperature	Final Temperature	k	$\beta$
Copper	30°C	405°C	226	234.5
Copper-clad steel (30% conductivity)	30°C	405°C	131.7	245
Copper-clad steel (40% conductivity)	30°C	405°C	152.1	245
Aluminium	30°C	325°C	148	228
Galvanised steel	30°C	400°C	78	202

**Table B1 - Assumptions for short-time rating assessment based on EA TS 41-24**

Material	Size	Cross-sectional Area	Rating 3s (1s)
Copper strip	25mm x 3mm	75mm <sup>2</sup>	9.2kA (15.9kA)
Copper strip	31mm x 3mm	93mm <sup>2</sup>	11.4kA (19.7kA)
Copper strip	25mm x 4mm	100mm <sup>2</sup>	12.3kA (21.2kA)
Copper strip	38mm x 3mm	114mm <sup>2</sup>	14.0kA (24.2kA)
Copper strip	31.5mm x 4mm	126mm <sup>2</sup>	15.4kA (26.8kA)
Copper strip	50mm x 3mm	150mm <sup>2</sup>	18.4kA (31.9kA)
Copper strip	40mm x 4mm	160mm <sup>2</sup>	19.6kA (34.0kA)
Copper strip	31mm x 6mm	186mm <sup>2</sup>	22.8kA (39.5kA)
Copper strip	38mm x 5mm	190mm <sup>2</sup>	23.3kA (40.3kA)
Copper strip	50mm x 4mm	200mm <sup>2</sup>	24.5kA (42.5kA)
Copper strip	38mm x 6mm	228mm <sup>2</sup>	28.0kA (48.4kA)
Copper strip	50mm x 6mm	300mm <sup>2</sup>	36.8kA (63.7kA)
Copper strip	50mm x 6.3mm	315mm <sup>2</sup>	38.6kA (66.9kA)
Copper strip	75mm x 6mm	450mm <sup>2</sup>	55.2kA (95.7kA)
Copper stranded	16mm <sup>2</sup>	16mm <sup>2</sup>	2.0kA (3.4kA)
Copper stranded	32mm <sup>2</sup>	32mm <sup>2</sup>	3.9kA (6.8kA)
Copper stranded	35mm <sup>2</sup>	35mm <sup>2</sup>	4.3kA (7.4kA)
Copper stranded	70mm <sup>2</sup>	70mm <sup>2</sup>	8.6kA (14.9kA)
Copper stranded	100mm <sup>2</sup>	100mm <sup>2</sup>	12.3kA (21.2kA)
Copper stranded	120mm <sup>2</sup>	120mm <sup>2</sup>	14.7kA (25.5kA)
Copper stranded	150mm <sup>2</sup>	150mm <sup>2</sup>	18.4kA (31.9kA)

**Table C1 - Short-time ratings for standard copper earthing conductor sizes**

NOTE: For tape with of 75mm it may be necessary to specially specify portable earthing end-clamps with this capability – ENA TS41-21 (portable earthing) caters for a maximum of 50mm width.

NB The ratings above assume brazed or welded joints. For bolted or crimped joints the de-rating multiplication factor shall apply as given in Table C3.

Material	Size	Cross-sectional Area	Rating 3s (1s)
Aluminium strip	25mm x 3mm	75mm <sup>2</sup>	5.6kA (9.7kA)
Aluminium strip	25mm x 4mm	100mm <sup>2</sup>	7.5kA (12.9kA)
Aluminium strip	25mm x 6mm	150mm <sup>2</sup>	11.2kA (19.4kA)
Aluminium strip	40mm x 4mm	160mm <sup>2</sup>	11.9kA (20.7kA)
Aluminium strip	50mm x 4mm	200mm <sup>2</sup>	14.9kA (25.8kA)
Aluminium strip	40mm x 6mm	240mm <sup>2</sup>	17.9kA (31.0kA)
Aluminium strip	50mm x 6mm	300mm <sup>2</sup>	22.4kA (38.8kA)
Aluminium strip	60mm x 6mm	360mm <sup>2</sup>	26.9kA (46.5kA)
Aluminium strip	80mm x 6mm	480mm <sup>2</sup>	35.8kA (62.0kA)

**Table C2 - Short-time ratings for standard aluminium earthing conductor sizes**

NOTE: For tape of 80mm it may be necessary to specially specify portable earthing end-clamps with this capability – ENA TS41-21 (portable earthing) caters for a maximum of 50mm width.

NB The ratings above assume brazed or welded joints. For bolted or crimped joints the de-rating multiplication factor shall apply as given in Table C3.

<b>Material</b>	<b>De-rating Factor - Bolted/crimped Joints</b>
Copper	0.83
Copper-clad steel (30% conductivity)	0.83
Copper-clad steel (40% conductivity)	0.83
Aluminium	0.90
Galvanised steel	0.84

**Table C3 – De-rating factor - bolted/crimped joint - final temperature limited to 250°C.**

The method of jointing may limit the rating. The permissible final temperature is reduced for bolted or crimped joints to 250°C. Table C3 gives the de-rating multiplication factor. NB: No de-rating should be applied to bolted joints onto substantial metalwork (e.g. HV steelwork etc).

<b>Material</b>	<b>100mm<sup>2</sup> Copper-equivalent Based on 3s Rating (mm<sup>2</sup>)</b>
Copper	100
Copper-clad steel (30% conductivity)	174
Copper-clad steel (40% conductivity)	151
Aluminium	165
Galvanised steel	280

**Table C4 - Material equivalent cross-sectional area table**

The minimum surface area formula given in EA TS 41-24 is:

$$I_g/S_t \ll 0.001\sqrt{(57.7/(\rho.t))} \quad \text{where}$$

- $I_g$  = current into earth electrode system (A)
- $S_t$  = total surface area of buried bare earth electrode ( $\text{mm}^2$ )
- $\rho$  = uniform equivalent soil resistivity ( $\Omega\text{m}$ )
- $t$  = fault duration (s).

Soil Type	Description
Silty soils	A fine soil with predominant particle size of 0.002-0.06mm
Sandy soils	A coarse soil with predominant particle size of 0.06-2mm
Gravelly soils	A coarse soil with predominant particle size of 2-60mm

**Table E1 - Non-corrosive soils suitable for import around copper earth electrode**

Note that gravelly soils may need to be sieved to remove large particles and ensure good contact with earth electrode.

Material
Bentonite
Marconite concrete
Low sulphur concrete

**Table E2 – Non-corrosive proprietary material suitable for import around copper earth electrode**

Table E3 lists materials which may cause accelerated corrosion of earth electrode. Geotechnical tests can be performed which may help quantify the problem. Difficulty may, however, be encountered in interpreting the results.

Soil Characteristics	Example Soil Types
High sulphide and carbon content	Cinders Pulverised fuel ash (PFA) Clinker
High organic acid content Soils with high content of decaying vegetation Soils with high humus content	Organic soils (peat, organic clay, silt or sand)
Strongly alkaline	Some clays
High dissolved salt content - sulphate and chloride	Poorly drained soils High humus soils

The acidity or alkalinity of the soil can be determined using the standard test method given in BS 1377-3. This determines the 'pH' of samples. Values less than 6 and greater than 10 are considered hostile to copper.

BS 1377 also defines how the 'redox potential' of a soil sample can be determined. This provides a means of assessing whether a soil is conducive to the activity of sulphate-reducing bacteria, which cause corrosion of metals.

Unusually low soil resistivity (e.g. <10 ohm metres) may also be indicative of corrosive soil. This is best measured using the Wenner four-probe test.

<b>Material</b>	<b>Grading Category for 20mm Single Size Aggregate</b>	<b>Target Wet Resistivity</b>	<b>Surface Dressing or Other Construction Thickness</b>
Limestone aggregate to BS EN 13043. See Note 1	14/20 G <sub>c</sub> 85/20	1500 ohm m	75mm with underlying geotextile membrane or 150mm without
Granite aggregate to BS EN 13043. See Note 1	14/20 G <sub>c</sub> 85/20	1500 ohm m	75mm with underlying geotextile membrane or 150mm without
Tarmacadam	N/A	1500 ohm m	75mm

**Table F1 –  
Approved materials and required specification for substation surface covering**

Note 1 Particles shall be hard, durable, inert and free from deleterious material (e.g. metallic compositions).

## **APPENDIX G**

### **SUPERSEDED DOCUMENTATION**

This document supersedes EE SPEC : 89/1 dated November 2007 which should now be withdrawn.

## **APPENDIX H**

### **ASSOCIATED DOCUMENTATION**

See section 3

## **APPENDIX I**

### **IMPLEMENTATION**

Immediate

## **APPENDIX J**

### **IMPACT**

This specification is relevant to WPD personnel involved in primary system design, preparation of invitations to tender, specification of requirements for competition in connections and associated projects. It is also relevant to external recipients associated with the above.

## **APPENDIX K**

### **KEY WORDS**

Competition in Connections, earth electrode, earthing, earthing system, hot site, hot zone, tender, invitation to tender