

EARTHING

This document is for internal and contract specific use only.

Disclaimer

NGG and NGET or their agents, servants or contractors do not accept any liability for any losses arising under or in connection with this information. This limit on liability applies to all and any claims in contract, tort (including negligence), misrepresentation (excluding fraudulent misrepresentation), breach of statutory duty or otherwise. This limit on liability does not exclude or restrict liability where prohibited by the law nor does it supersede the express terms of any related agreements."

TABLE OF CONTENTS

PURPOSE AND SCOPE	1
PART 1 – PROCEDURAL	1
1 GENERAL REQUIREMENTS	1
2 PERFORMANCE REQUIREMENTS.....	20
3 DESIGN INFORMATION	21
4 TEST REQUIREMENTS	21
5 ACCEPTANCE PROCEDURE	22
6 REFERENCES	22
PART 2 - DEFINITIONS AND DOCUMENT HISTORY	24
7 DEFINITIONS	24
8 AMENDMENTS RECORD	25
9 IMPLEMENTATION	26
PART 3 - APPENDICES.....	27
APPENDIX A: MEASUREMENT METHODS	27

PURPOSE AND SCOPE

This document defines the functional performance and test requirements for earthing systems forming part of the National Grid System and protected by fast acting protection systems *. It supports the more general conditions defined in the companion documents TS 1 and TS 2.1.

The requirements of this document shall apply to new substations, cable sealing end and tower constructions and where reasonably practicable to extensions or modifications of existing substations and cable sealing ends and tower refurbishment.

Where a substation, cable sealing end or tower is being extended or modified, National Grid will state if it is necessary to control the earth potential rise (EPR) in accordance with 1.2. If not stated, this requirement does not need to be applied.

**Note: Fast acting protection systems are those designed to achieve a target total fault clearance time of less than 200ms.*

PART 1 – PROCEDURAL

1 GENERAL REQUIREMENTS

The earthing system shall comply with BS EN 50522, EA TS 41-24 and BS 7430, unless otherwise stated.

1.1 Statutory Requirements

The earthing system shall be designed and installed to comply with all relevant statutory instruments.

Specifically, The Electricity Safety, Quality and Continuity Regulations 2002 require that:

"A generator or distributor shall ensure that, so far as is reasonably practicable, his network does not become disconnected from earth in the event of any foreseeable current due to a fault".

Further requirements are contained in the Electricity at Work Regulations 1989 and Management of Health and Safety at Work Regulations 1999.

1.2 Earth Potential Rise (EPR)

- 1.2.1 The safety of all persons on high voltage sites, as well as in the immediate environs of such sites, and persons who may contact any conducting services to, or passing through such sites, is dependent on the design of the earthing system and its associated electrical isolation. The design of the earthing system at substations shall limit the step and touch potentials to safe levels given in Table 1.

	Max. Voltage for Touch	Max. Voltage for Step
Chippings surface (150mm)	2.06kV	Limit could not foreseeably be exceeded
Chippings surface (75mm)	1.78kV	
Soil surface	1.57kV	

Table 1 Touch and Step Potential Limits

The limits in Table 1 assume a 200ms clearance time, a 1m step distance, a footwear resistance of 4kΩ per shoe, and effective earth foot resistance values respectively. They are based upon the approach agreed within BS EN 50522 UK national annex 'A'.

Informative: Current design practices show that touch voltage has always been the more critical design criteria, comparing to step voltage. As a key change to its 1994 version, IEC 60479-1 (2005) has since introduced the remarkable heart factor of 0.04 for step voltage scenarios, which directly resulted in the values 'Maximum Voltage for Step' to be in excess of 130kV. As the step voltage limit values are not foreseeable to be exceeded in reality, following the convention of BS EN 50522 (2012), they are not listed in Table 1 above. If required, Asset Policy can provide the values.

- 1.2.2 The management of EPR at transmission towers shall also be in accordance with PS(T) 045 and TGN(E) 199.
- 1.2.3 In the event that an insulating coating is required to be applied to the tower legs in order to manage the risks associated with touch potentials, then the coating specification shall comply with the minimum requirements below:
- a) Minimum Rated voltage withstand: 50kV
 - b) Coverage: From ground level to 2.5m above ground level
 - c) Minimum Service Life: 10 years
 - d) The coating shall not serve to aid climbing of the tower
 - e) The coating shall not prevent the fitting of step bolts
 - f) The coating shall be resistant to minor impact damage
 - g) The coating shall be dark or light grey and shall generally be unobtrusive
- 1.2.4 Cable sealing ends shall be treated as substations unless otherwise agreed by National Grid.
- 1.2.5 Critical third party EPR impact voltage thresholds via proximity effects are given below

- 1.2.6 Critical third party EPR impact voltage thresholds via proximity effects are given below

Third Party Infrastructure	Threshold Limit Voltage
Domestic residence or commercial property	1700V
Large hazardous process plant e.g. refinery	650V
Railways	645V

Table 2 Third Party Impact Threshold Voltages via Proximity Effect

****:** Proximity effect refers to EPR conduction via the ground

- 1.2.7 Where a National Grid substation provides a HV connection to a third party, the applicable threshold limit values via conduction are given below.

Third Party Infrastructure	Threshold Limit Voltage
Domestic residence or commercial property	Not Applicable
Large hazardous process plant e.g. refinery	650V
Railways	645V

Table 3 Third Party Impact Threshold Voltages via Conduction

*****:** Conduction refers to electrical conduction via metallic conductors.

- 1.2.8 The design of the earth electrode system (whether this is as a result of adding to an existing system or the installation of new system), shall be optimised in so far as is reasonably practical to ensure third party impact threshold voltages are within the limits in Tables 2 and 3. In particular, consideration shall be given to the arrangement of the electrode system and the use of all land within the substation boundary. It is only necessary to use land outside the substation boundary (within National Grid's ownership) if stated by National Grid. The earth electrode depth and geometry shall be optimised to make use, as far as practicable, of lower resistivity ground strata.

Where reasonably practicable, the earthing system shall be designed using an earth return current which is 20% greater than that calculated by National Grid, to allow for future increases in system fault current.

- 1.2.9 Calculations to design the main earth system shall be carried out using the MALZ module of CDEGS software package (**C**urrent **D**istribution, **E**lectromagnetic Fields, **G**rounding and **S**oil Structure Analysis). The design models produced shall be made available once completed and shall become the property of National Grid as part of the contract.
- 1.2.10 Communication cables connecting to all National Grid substations must be fitted with appropriate electrical isolation in accordance with TGN(E) 133.

1.3 Earth Electrodes

- 1.3.1 Earth electrodes shall be designed to operate satisfactorily during faults, taking into account the area of the electrodes in contact with earth, the soil resistivity and earth electrode current magnitude and duration, in accordance with BS 7430. The fault duration times to be used for rating the electrodes are 1 second for 275kV and 400kV and 3 seconds for all other voltages.
- 1.3.2 Buried bare copper horizontal earth electrodes shall be installed at around 500mm depth. If the indigenous soil is hostile to copper, see section 3.1.1 (b), the electrode shall be surrounded by 150mm min of non-corrosive soil of fine texture, firmly rammed. Conductors

installed in ploughed farmland shall be buried at least 1m deep, at all points, measured from undisturbed ground level.

- 1.3.3 Earthing electrodes should not be directly buried in high resistivity materials such as are commonly encountered as back-fills. These could include for example MOT Type 1 crushed concrete aggregate. Sand is also not suitable. In these cases, the electrodes shall be surrounded by 150mm min of non-corrosive soil of fine texture, as per clause 1.3.2. Alternatively, the properties of any backfill materials may be established through laboratory testing and shall be deemed acceptable if commensurate with the indigenous ground properties.
- 1.3.4 Where buried earthing conductors are exposed to indigenous soils that are hostile to copper, stranded copper conductors are not permitted within the earthing design.
- 1.3.5 Driven rod electrodes in accordance with EA TS 43-94 shall be used to exploit lower resistivity ground strata where present to reduce the EPR in accordance with clause 1.2. Where the ground is hard and rods cannot be driven, consideration shall be given to drilling holes to install the rods and back filling with a suitable low resistance fill material.
- 1.3.6 Special types of earth rods, e.g. Chem-Rod, may be employed, provided conventional techniques could not meet the design requirements. Due to the use of chemicals, such cases should be considered thoroughly, taking into account the environment concerns and special maintenance needs. Appropriate agreement must be obtained with National Grid prior to use.
- 1.3.7 Where beneficial, reinforcing steelwork incorporated within piling may be connected to the MES for the purpose of equipotential bonding and/or to form part of a common bonding network (CBN). However, care must be taken to ensure that the current carrying capacity of the steelwork is not exceeded.

Although it is acknowledged that buried concrete encased steel reinforcement can, depending on certain conditions, constitute an effective earth electrode, it should not normally be relied upon to provide an earth electrode as part of the earthing system design.

Where reinforcement steelwork in piles is connected to the MES, connections shall be made to the vertical steel bars within the pile cap. Connections brought out through the pile cap shall be provided with appropriate means to prevent moisture ingress into the cap. Current carrying connections to and within the steelwork shall be in accordance with TS 2.1. Fortuitous connections must not be relied upon. Welded connections are preferred.

Where sheet steel piles of the interlocking kind are used as an earth electrode, connections shall be made to each pile.

1.4 Earth Electrode Arrangement

- 1.4.1 Unless otherwise agreed by National Grid, the earthing electrode arrangement shall be based on a peripheral buried main bare earthing conductor generally encompassing the plant items to be earthed, with buried spur connections, from the main conductor to the items of plant. The main earthing conductor shall be augmented with inter-connected buried bare cross-connections to form a grid. In addition, where beneficial, groups of earth rods distributed around the periphery shall be connected to this main earthing conductor.
- 1.4.2 For indoor substations the earthing grid shall be installed with spur connections to the steel reinforcing mat of the concrete floor, every 20m. Additionally, a second peripheral main earthing conductor shall be buried at 1m distance from the building, which shall be bonded to the first main conductor, and to the building if it is metalclad, both at 20m intervals. Earth rod groups shall be connected to the second peripheral conductor as described in clause 1.4.1.

1.5 Test Facilities

- 1.5.1 In order to facilitate testing of all earth electrode groups, a section of conductor connecting to each group shall be made accessible and shall have dimensions that would fit inside 50mm diameter circular clamp meter jaws (min length 75mm). An example of how this can be achieved is shown in Figure 1. This section of conductor shall be a part of a spur connection to the rod group, i.e. so that all the test current flows into the rod group and is not diverted into the main earth system. All testing points shall be identified both on the design earthing drawings and within the test pit at site.
- 1.5.2 Disconnectable links must not be fitted in the connections from the main earth system to terminal towers or rod groups or in the connections between main earth systems, e.g. between earth systems on joint sites.



Figure 1 An example of earthing connection box with test facility *

**Note – The image shown above is without a lid and is meant to simply depict a surface accessible earth test box. This box example is suitably dimensioned to allow the testing of earth rod groups without disconnection in accordance with sections 1.5 and 1.6.*

- 1.5.3 Where rod groups have not been utilised, and where practicable, a minimum number of 4 earth rod electrodes shall be installed to allow routine sample testing to check for corrosion. As in clause 1.5.1, a section of conductor connecting to each rod shall be made accessible and shall have dimensions that would fit inside 50mm diameter circular clamp meter jaws (min length 75mm). All testing points shall be identified both on the design earthing drawing and within the test pit at site.

1.6 More Than One HV Substation

- 1.6.1 Where there is more than one National Grid substation on the same site, a separate earth grid shall enclose each substation and these grids shall be connected together at the extremities by at least two fully rated conductors ideally taking secure separate physical routes. In order to facilitate testing of the interconnections, the conductors connecting the systems together shall each be made accessible at a designated point. At this point the conductors shall have dimensions which would fit inside a 50mm diameter circular clamp meter jaws (min length of conductor 75mm). An example of how this can be achieved is shown in Figure 1. All testing points shall be identified both on the design earthing drawing and within the test pit at site.
- 1.6.2 Where a National Grid substation is located on the same site as another user's substation, the earthing systems shall be interconnected as defined by National Grid. All testing points shall be identified both on the design earthing drawing and within the test pit at site.

1.6.3 Measures shall be taken to ensure that persons can not come into contact with hazardous transferred potentials between substations or directly connected customers, particularly where sites are separated. Where control of these potentials requires measures to be taken by a third party, National Grid shall be informed by the supplier at the time of production of the earthing design.

1.6.4 In all cases where HV earthing systems are connected together, disconnectable test links shall not be fitted.

1.7 Equipment Connected to the Main earth system

1.7.1 The following items of equipment shall be connected to the main earth system by a fully rated conductor:

- a) All points which may form the earth of a high voltage fault path.
- b) Transformer winding neutrals required for HV system earthing. For 66kV and below, the connection may be via earthing resistors or other current limiting devices.
- c) In the case of a manually operated earthing or HV switch, the mechanism box shall be bonded to the main earth system. For equipment on concrete structures, a 70mm² min dedicated conductor is required and shall be directly connected to earth mat, rather than teed off the earth tapes for earth switch arms. For equipment on steel structures, as long as dedicated tapes are installed for the structures (and for the earth switch arms if applies), the steel structures can be used to earth the mechanism boxes. For both cases, Earth tapes under operators' stance are desirable but not necessary.

1.7.2 All metalwork, e.g. panels, cubicles, kiosks etc., including the steelwork of buildings, shall be bonded to the main earth system, preferably by a conductor of no less than 70mm² cross section or a strip conductor no less than 3mm thick. The minimum conductor can be reduced to 16mm² where it is not reasonably practicable to install 70mm² conductors, provided the connection is secure.

1.7.3 For all substation fully rated flexible insulator strings, shunt conductors should be used between the arcing ring adjacent to the structure and the earth bars on the structure, so as to by-pass the major proportion of fault current under flashover conditions from the end fittings. The shunt conductor(s) shall be black PVC sheathed and flexible (see BS 638-4:1996 and BS EN 60228:2005 for possible candidates) with suitable joint arrangement.

1.7.4 Metallic trench covers shall be earthed to cater for the possibility of an earth fault on cabling in the trench and to cater for the possibility of induced or transferred potentials. To achieve this, metal trench covers may be laid on conducting support(s) that shall each be connected to the main earth system by a conductor as specified in clause c) above.

1.8 Installation

1.8.1 Earthing conductors laid in trenches in outdoor substation compounds should be avoided where possible due to the vulnerability of the copper to theft. Where this is unavoidable, the earthing conductor should be protected from theft using the techniques detailed within section 1.8.7.

Where a trench contains power cables and/or multicore cables, the earthing conductor shall be fixed to the walls of the trench approximately 100mm from the top to maintain separation from the cables.

1.8.2 Due regards shall be given to the possibility of mechanical damage to buried conductors and, where necessary, either marker tapes and/or mechanical protection shall be installed. A separation of at least 500mm to civil works, such as drainage pits, shall be maintained.

Conductor runs above ground shall be designed to minimise the possibility of mechanical damage.

- 1.8.3 When laying stranded conductors, care shall be taken to avoid distorting individual strands.
- 1.8.4 Where below ground earthing conductors cross, they shall be jointed (other than in the case of rod groups where these must be maintained separate to permit testing). Bolted joints are not acceptable below ground other than for earth rod screw couplings which shall be thoroughly greased. Connections to buried earth rods shall be welded in accordance with TGN(E) 187.
- 1.8.5 Where earthing conductors terminate above ground, the connections shall as far as is reasonably practical be made onto equipment surfaces in the vertical plane to avoid standing water. Connections to metal cladding of buildings shall be made on the inside of the building. All joints shall be installed in accordance with TGN(E) 187. Moreover, all bolted joints shall be situated at least 150mm above ground level. Bolts and nuts with security features, e.g. as listed in 1.8.8.1, shall be used, particularly to make the joints where earth tapes are connected to equipment tank/base or structures.
- 1.8.6 Aluminium conductor used for earthing systems shall only be installed above 250mm from ground level. All joint interfaces between the below ground copper earth conductors and the above ground aluminium earth conductors shall be jointed to manage any potential galvanic corrosion issue, to clause 1.8.5. Stampings on conductors should be in accordance with clause 1.8.8.1.
- 1.8.7 All vulnerable shallow buried earth tapes (tapes installed with less than 400mm of covering), shall be protected from theft at 2m intervals with either concrete anchors or driven earth rods.
- 1.8.8 Due to their vulnerability to theft, all above ground earthing conductors shall be fixed firmly and tidily to structures at a spacing of no more than 200mm between fixings. The fixings shall not promote galvanic corrosion. Where earthing conductor fixing systems require the earth conductor to be drilled, checks shall be undertaken to ensure that the loss of cross sectional area of the earthing conductor does not de-rate its operational performance requirements. Due to the lack of security fixing techniques for stranded conductors, where reasonably practicable, flat copper tapes should be used for all above ground earthing conductors.

All above ground earth tape shall be proactively protected from theft using the following techniques:

- 1.8.8.1 All copper and aluminium earth tape conductors shall be stamped continuously throughout its length with the markings "PROPERTY OF NATIONAL GRID" to deter theft and devalue the product. There should be minimal spacing between the start of the stamping of each sentence. At the completion of the installation, the stampings should be made visible as far as reasonably practicable.
- 1.8.8.2 Where concrete structures are used within the substation design solution and/or where earth tapes run across equipment concrete foundation pads, stainless steel concrete anchor pins shall be used to secure the copper earth tapes in place. The anchor pins shall be 6mm (for tapes 50mm in width) in diameter with a head diameter in excess of 12mm, installed to a minimum depth of 40mm into concrete. The shape of the anchor pin head shall be shaped to resist impact chiselling and interference. All earth conductors shall be fixed to equipment concrete foundation pads for a minimum depth of 300mm below the finished surface levels to deter interference. Figure 2 shows a typical security fixing on concrete structures.

Cares should be taken to avoid forming conductive loops, when pins are in contact with rebars, which will probably result in inadvertent circulating current in earthing installations.



Figure 2 Typical images showing installed stainless steel anchor pin solutions onto concrete structures and equipment foundation pads.

- 1.8.8.3 Where steel structures are used within the substation design solution, stainless steel panel bolts and shear nuts should be used to secure the earth tapes to the equipment structure. The bolts should utilise a keyed design to deter interference and be sized in appropriate lengths to accommodate the structure profile thicknesses. The bolt head diameter shall be a minimum of 12mm, shaped to resist impact chiselling. The bolts should have a sectional thickness diameter of 6mm (for tapes 50mm in width). Shear nuts shall be designed to deter interference once fully installed. A typical installation is illustrated in Figure 3.



Figure 3 Typical images showing stainless steel keyed bolts and sheer nuts (unsheared)

- 1.8.8.4 On occasions, steel support structures used within the substation design solution may not, because of their physical construction or the materials used, lend themselves easily to direct security bolting of copper earth tapes as described in section 1.8.8.1. Until such structure designs are modified to accommodate direct fixings, alternative arrangements to deter theft must be considered. One such alternative approach is to encapsulate and fix all above ground earth tape within a steel capping cover system before fastening to the design points made available on the structure steelwork. The perceived benefit from taking this approach is to make the solution difficult to separate into its component parts, making it inherently more difficult to steal, to manhandle and to sell on without its value being considerably reduced. Figure 4 depicts an exemplar installation.



Figure 4 Typical images showing encapsulation of above ground copper tape within capping on a structure that does not lend itself to a direct bolting approach.

- 1.8.8.5 On National Grid sites, which benefit from enhanced security level due to CNI/ISS schemes, **indoor installations** may adopt larger secured fixing intervals of not more than 1000mm. For sites of normal security level, small amount (i.e. $\leq 40m$) of earth tapes installed **within buildings** can also be securely fixed at intervals up to 1000mm.

1.9 Portable Earthing

- 1.9.1 Loops for portable earths shall be provided on the earthing conductor at each location where portable earths may be required to be applied. The loops shall be fully rated and suitable for National Grid standard portable earthing equipment, and shall be made of copper. The loops shall be not less than 230mm long and shall be 75mm clear of the earthing conductor. Loops for portable earths shall be installed at a convenient height and shall be directly connected to the MES by copper conductors, i.e. not via steel structures. Above ground earthing tapes should be securely fixed to deter theft in accordance with section 1.8.

The loops for portable earths shall employ designs which minimise the provision of climbing aids. For instance, the loops with tops inclined at degrees $\geq 45^\circ$, shall be adopted for vertical installations. Wherever this is not implementable, they should be positioned following consultation with National Grid in a way to deter them being used as climbing aids.

The rating of multiple portable earth leads shall be as listed in Table 4.

Number of leads (150mm ² aluminium)	132/66kV	400/275/13kV
1	17.5kA	23.4kA
2	31.5kA	42.12kA
3	47.25kA	63.18kA
4	63kA	-

Table 4 Ratings for multiple portable earth leads

1.10 Steel Support Structures

- 1.10.1 Where the current carrying capacity of steel support structures is at least equal to the switchgear rating, it is preferred that the structure is utilised to form part of the connection to the main earthing system, in which case there is no need to fix an earth conductor along this section.
- 1.10.2 Where a steel structure is relied upon to provide an earth connection for supported equipment, current carrying joints across the earth path within 2.4m of ground level shall be bridged across with fully rated earth tapes in accordance with TGN(E) 187. Above 2.4m, the