ENGINEERING DESIGN STANDARD

EDS 06-0014

SECONDARY SUBSTATION EARTHING DESIGN

Network(s): EPN, LPN, SPN

Summary: This standard details the earthing design requirements for secondary distribution substations.

Author: Stephen Tucker Date: 09/11/2018

Approved By: Paul Williams Approved Date: 23/11/2018

This document forms part of the Company’s Integrated Business System and its requirements are mandatory throughout UK Power Networks. Departure from these requirements may only be taken with the written approval of the Director of Asset Management. If you have any queries about this document please contact the author or owner of the current issue.
Revision Record

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**Reason for update:** Document revised to include updated earthing arrangements, BS EN 50522 safety voltage limits and to clarify points raised by internal and external designers.

**What has changed:**
- Earthing changes from EBB 07-0050 incorporated.
- All supporting data moved to EDS 06-0012.
- Design criteria added (Section 4).
- Design flowcharts Figure 6-1 and Figure 7-1 revised (Section 6 and 7.1).
- Further detail on the use of earthing piles included (Section 7.3 and 10.4).
- BS EN 50522 touch and step voltage limits introduced (Section 7.5).
- Transfer voltage calculation requirement clarified (Section 7.7).
- Electrode surface area current density calculation clarified (Section 7.9).
- Further guidance on earthing at existing substations included (Section 9).
- GRP arrangements revised to align with EDS 07-3102 (Section 8).
- Customer supply arrangement revised (Section 8.5).
- Metalwork bonding requirements enhanced (Section 10.5).
- Revised guidance on substations near livestock, railways, cathodic protection systems, fuel filling stations and lightning protection systems included (Section 11).
- Earthing report example updated (EDS 06-0014F).
- Earthing arrangement models updated (EDS 06-0014G).
- Ground return current and electrode surface area current density moved to EDS 06-0012.

EDS 06-0014C 'Design and Construction Form' withdrawn.

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Updated to ensure consistency with EDS 07-0102 and ECS 06-0023.
- Design flowchart revised (Section 7.1).
- Lower rebar connection removed from all earthing arrangements (Section 8.1).
- Integral and basement substation design with embedded mesh introduced (Section 8.4).
- Use of network contribution (Section 7.6), explanation of ground return current (Appendix H) and worked example from ICP addendum incorporated (Appendix F).
- Pipelines (Section 11.11) and fuel filling stations (Section 11.13) added to special situations.
- Standard arrangement resistances and touch/step voltage percentages revised, typical ground return current values added, touch/step voltage limits updated to include tarmac and longer fault clearance times and typical network contribution values included.
- Simple rod and conductor electrode options added (Appendix B).
- Design form revised (Appendix C).
- Use of vertical steel piles (Section 7.6) and surface current density calculation added (Appendix I).

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Version 1 (previously Earthing Manual Section 5) withdrawn and interim guidance provided.

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Original.
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1 Introduction

This standard details the earthing design requirements for secondary distribution substations. It is intended to provide guidance for UK Power Networks designers/planning engineers and external connection providers to ensure that designs satisfy the requirements of the latest standards.

The construction of the earthing for secondary substations is detailed ECS 06-0023.

The earthing arrangements have been developed to cover a range of standard substation designs and are supported by a standard design procedure to allow optimal earthing designs to be produced. There will be some situations where standard arrangements are not suitable, and it is the responsibility of the designer/planning engineer to exercise a degree of judgement, and to seek help from an earthing specialist if the appropriateness of a standard arrangement is in doubt.

The legacy approach to secondary substation earthing design was based on one or two earth rods and combining HV and LV earths if the measured earth resistance was less than 1 ohm. These rules relied on metallic sheathed cables providing a grading effect (hence controlling touch and step voltages) and reducing the overall substation earth resistance (hence reducing the earth potential rise) together with low values of earth fault current.

However many parts of UK Power Networks have high earth fault levels that require additional earthing measures. Furthermore, plastic sheathed cables have been in use for many years and the composition of the cable network is changing; the previous grading benefit provided by metallic sheath cables can no longer be exploited at new and refurbished sites. Although more robust earthing arrangements can overcome some of these limitations the magnitude of the earth fault levels remains, therefore the legacy approach can no longer be justified and more detailed attention to earthing design is required.

This standard is based on the principles of ENA TS 41-24 and BS EN 50522, and seeks to achieve an earthing design with acceptable touch and step voltages and a low earth potential rise to allow the HV and LV earths to be combined. The main requirements include:

- A buried ring electrode around the site or an embedded mesh to control the touch and step voltages.
- Calculation of a site specific earth resistance to achieve acceptable touch and step voltages and allow the HV and LV earths to be combined.
- In some situations additional earth electrode consisting of buried conductor and/or rods may be required to achieve the calculated earth resistance.
- Dedicated vertical piles designed for earthing may be used in place of earth electrode and/or standard vertical piles may be used as supplementary earthing in additional to earth electrode.
- The contribution of the wider network may be used to supplement the main earthing system if appropriate; however the touch and step voltages shall be safe before any network contribution is considered.
- The earthing systems for substations supplied directly from an overhead line network may require additional precautions (e.g. additional ring electrode and/or a concrete or tarmac surround) to achieve acceptable touch and step voltages.
- Conductor sizing is based on a common approach to all three network areas.
- The earthing arrangements are included in the EDS 07-3102 suite of substation civil drawings.
2 Scope

This standard applies to the earthing design for all new secondary substations and existing secondary substations where a material alteration is to take place, e.g. switchgear replacement, fencing replacement etc. on the 20kV, 11kV and 6.6kV distribution networks.

The principles may also be applied to the earthing for 3kV and 2kV substations.

Secondary substation earthing construction is covered in ECS 06-0023.

Further guidance for customers on substation earthing is available in EDS 06-0019.

The earthing design for pole-mounted equipment, LV networks (including LV overhead networks) and customer LV installations are covered respectively in EDS 06-0015, EDS 06-0016 and EDS 06-0017.

3 Abbreviations

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tr>
<td>CNE</td>
<td>Combined Neutral Earth. A CNE cable has a combined neutral and earth metallic outer sheath with a covering and is most commonly used in a PME (protective multiple earthing) LV earthing system</td>
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<td>COLD Site</td>
<td>A COLD site is a grid, primary or secondary substation where the earth potential rise is less than 430V or 650V (for high reliability protection with a fault clearance time less than 200ms)</td>
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<td>EPR</td>
<td>Earth Potential Rise. EPR is the potential (voltage) rise that occurs on any metalwork due to the current that flows through the ground when an earth fault occurs on the HV or LV network. <strong>Note:</strong> Some current will flow through the cable sheath back to the source and some will flow through the ground, it is only the current that flows through the ground that causes the earth potential rise. Historically this has also been known as rise of earth potential (ROEP).</td>
</tr>
<tr>
<td>HOT Site</td>
<td>A HOT site is a grid, primary or secondary substation where the earth potential rise is greater than 430V or 650V (for high reliability protection with a fault clearance time less than 200ms)</td>
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<tr>
<td>IDNO</td>
<td>Independent Distribution Network Operator</td>
</tr>
<tr>
<td>NetMap</td>
<td>UK Power Networks graphical information system (GIS)</td>
</tr>
<tr>
<td>RCD</td>
<td>Residual Current Device</td>
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<tr>
<td>SNE</td>
<td>Separate Neutral Earth. An SNE cable has separate neutral and earth conductors. Generally the neutral conductor is a fourth core and the earth conductor forms a protective sheath.</td>
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<tr>
<td>Step Voltage</td>
<td>The voltage difference between a person’s feet assumed to be 1m apart</td>
</tr>
<tr>
<td>Touch Voltage</td>
<td>The voltage difference between a person’s hands and feet when standing up to 1m away from any earthed metalwork they are touching</td>
</tr>
<tr>
<td>Transfer Voltages</td>
<td>The voltage transferred by means of a conductor between an area with a significant earth potential rise and an area with little or no earth potential rise, and results in a voltage difference between the conductor and earth in both locations</td>
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4 Design Criteria

The most general, and overriding requirement is that the installation shall be designed to prevent danger, as required by ESQC Regulations. In terms of earthing, this equates to prevention of electric shock and fire/thermal damage throughout the lifetime of the installation.

The design and installation of an appropriate earthing system will ensure that a suitably low impedance path is in place for earth fault currents and minimise touch and step voltage hazards.

The main objectives are to:

a) design and install an earthing system that provides sufficient safety with regard to touch and step voltage limits;

b) conform with the requirements of UK Power Networks earthing standards, BS EN 50522 and BS 7430; and

c) satisfy UK Power Networks that the site is safe to energise and operate.

5 Design Requirements

Substation earthing provides the following function:

- To pass the fault current during an earth fault back to the system neutral and operate the source protection.
- To prevent dangerous voltages appearing at the substation and causing danger to staff or the public.
- To prevent dangerous voltages appearing on the customers' LV neutral/earth.
- To comply with the requirements for substation LV earthing for PME systems.

To satisfy this the following design requirements shall apply:

- A maximum HV electrode earth resistance of 10Ω to operate the HV protection.
- A maximum earth potential rise of 2kV.
- A ring electrode (or embedded mesh) enclosing and bonded to all equipment and rebar bonding to ensure the touch and step voltages are within acceptable limits.
- Earth electrode sizes based on source earth fault levels.
- The earth potential rise limited to 430V as far as reasonably practicable (provided the HV protection operates within 1 second for faults at the substation), to allow the HV/LV earths to be combined and prevent dangerous voltages appearing on the LV system; if this limit cannot be satisfied the HV/LV earths shall be separated.
- A maximum LV earth resistance of 20Ω (in accordance with ENA EREC G12) where a separate LV earth is required.
- Touch voltage within the acceptable limits using the substation standalone electrode system only and shall not rely on any parallel contribution from the network.
- The proposed earthing system can be achieved on-site to avoid re-design at the time of installation.

Refer to EDS 06-0012 for a more detailed explanation of earth potential rise, the voltage limits and the associated calculations.

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2 This should ensure that the touch and step voltages within and around the substation are safe for the expected life of the substation no matter how the network changes.
6 Preliminary Earthing Assessment

A preliminary earthing assessment for a secondary substation should be carried out using the flowchart in Figure 6-1 to determine if there are any external factors that are likely to affect the earthing design.

START

Overhead site?

Yes → Refer to EDS 06-0015

No →

Existing secondary substation or fence replacement?

Yes → Refer to Section 9

No →

Located within grid or primary site?

Yes → Grid or primary substation HOT?

Yes → Use combined HV/LV earth connected to site earth

No → Use combined HV/LV earth connected to site earth (not suitable for providing external supplies)

No →

Special situation?

Yes → Refer to Section 11 then carry out earthing design

No →

Propose use of piles for earth electrode system?

Yes → Discuss design with UK Power Networks before starting

No →

Joint site with customer?

Yes → Consider use of earthing specialist to carry out detailed design

No →

Non-standard/bespoke earthing arrangement?

Yes → Employ earthing specialist to carry out detailed design

No → Carry out earthing design in accordance with Section 7

Figure 6-1 – Preliminary Earthing Design Assessment
7 Design Procedure

7.1 Overview

An overview of the secondary substation earthing design procedure is shown in Figure 7-1. The flowchart includes references to the sections that follow to provide further detail on each of the steps in the flowchart.

The earthing design tool (Appendix E) should be used by UK Power Networks staff to carry out the earthing design to ensure that it complies with this standard and the design is correctly documented.

UK Power Networks designers and planning engineers shall provide the following for all secondary substation projects:

- A completed earthing design form.
- A completed earthing construction form.
- A copy of the relevant earthing arrangement drawing from EDS 07-3102.

External connection providers shall provide the information detailed in Section 12 to allow UK Power Networks to assess the design.

Note: If a non-standard design is required an earthing specialist shall be employed to carry out the appropriate design and calculations and produce a supporting report and drawing.

7.2 Information Requirements

The following information is required to design a secondary substation earthing system:

- Source grid/primary substation earth fault level and earth resistance value.
- Earth fault level at the new secondary substation.
- Source substation classification (HOT/COLD) and the associated earth potential rise for HOT sites.
- Details of the cable or overhead line network between the source and the new secondary substation including lengths, types, and the cable sheath cross-section and material (where appropriate) etc.
- Distance of the secondary substation from the source substation.
- Soil resistivity at secondary substation location.
- Fault clearance time for an earth fault at the new substation.

Refer to Appendix A for UK Power Networks data sources.

Where required UK Power Networks will provide the network specific data to enable an external connection provider to design a suitable secondary substation earthing system.
Select substation earthing arrangement

Obtain Data

Standard substation arrangement suitable?

Yes

No

Employ earthing specialist to carry out design

Determine secondary substation earth resistance

Determine ground return current

Calculate EPR

Recalculate earth resistance

Install additional earth electrode to reduce earth resistance or consider different design

Determine touch voltage limit for fault clearance time

Calculate touch voltage

Touch voltage < touch voltage limit?

Yes

No

EPR < 2x touch voltage limit?

Yes

No

EPR < 430V?

Yes

No

Evaluate network contribution

Re-calculate EPR

Source substation EPR >430V and supplied via continuous cable?

Yes

No

Calculate transfer voltage

EPR <430V?

Yes

No

Use combined HV/LV earth with calculated HV resistance

COLD Site

Check electrode surface current density

Acceptable?

Yes

No

Specify additional buried earth electrode

HOT Site

Document design and determine electrode and other earthing requirements

Re-evaluate design or consider use of earthing specialist to carry out detailed design

Re-calculate EPR

Use separated HV/LV earths, calculated HV resistance and 20 ohm LV earth resistance

Figure 7-1 – Earthing Design Procedure Flowchart
7.3 Earth Resistance

Determine the earth resistance as follows:

1. Select a standard earthing arrangement based on the type of secondary substation (e.g. GRP, brick-built, integral, padmount, timber fence etc.) from Section 8. The designs use 2.4m earth rods but additional (or longer) rods and electrodes can be used to provide the desired value of earth resistance.

2. Estimate the substation HV electrode resistance ($R_{\text{SecSub}}$) for the substation earthing arrangement and the soil resistivity.

   **Standard substation earthing arrangement earth resistance data** is available from EDS 06-0012 Appendix A.

   **Soil resistivity data** is available from the Earthing Design Tool or NetMap\(^3\) (refer to EDS 06-0018 for further information) or the British Geological Survey.

3. Dedicated vertical piles which have been specifically designed for earthing may be used in place of earth rods for integral and basement substations which form part of an overall building design. This approach shall be agreed and the design approved by UK Power Networks before commencing work. Refer to Section 10.4 for information.

4. If the earth resistance is greater than 10 ohms, longer earth rods or additional earth electrode should be considered to reduce the earth resistance further.

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\(^3\) UK Power Networks GIS system.
7.4 EPR Calculation

Calculate the EPR as follows:

1. Determine the source (primary or grid) substation earth resistance (or assume 0.1 ohms if not available).

   Grid and primary substation earthing data is available from the asset register. Refer to Appendix A for further information.

2. Determine the earth fault current at the secondary substation ($I_f$). If the earth fault level at the secondary substation is not available the earth fault level at the source substation will provide a good (but pessimistic) approximation.

   Refer to Appendix A for further Information on obtaining earth fault levels.

3. Calculate the percentage of fault current ($%I_{gr}$) that will flow through the ground.

   - For overhead supplied sites, or sites with any overhead line in the supply circuit, a ground return current of 100% shall be used.
   - For entirely cable supplied sites a ground return current of 40% of the total earth fault current can be assumed as a first estimate or a more accurate value can be calculated. Refer to EDS 06-0012 Appendix E for calculation methods and equations.

   Note: It is likely that there are multiple cable types between the secondary substation and the source substation. The initial calculation should be based on the smallest size cable; however modelling each cable separately will provide a more accurate value and a lower value of EPR.

4. Use this percentage ($%I_{gr}$) to calculate the value of the ground return current $I_{gr}$:

   $I_{gr} = %I_{gr} \times I_f$

5. Use the calculated value of $I_{gr}$ and the value of $R_{SecSub}$ to calculate the EPR for the site:

   $EPR = I_{gr} \times R_{SecSub}$
7.5 Safety Calculations

The touch and step voltages shall be based on the EPR calculated using the standalone earth resistance from the substation earthing arrangement and any additional earth electrode. The parallel earth resistance contribution from the network shall not be used in the safety calculations.

The touch and step voltages are calculated as follows:

1. To calculate the touch voltage and determine whether it is acceptable the following information is required:
   - Proposed earthing arrangement for the secondary substation.
   - Substation surface type.
   - Calculated value of EPR.
   - Fault clearance time.

   **What fault clearance time to use?**
   
   The fault clearance time is the sum of the protection relay (source or upstream) and the circuit-breaker operating times. A value of 1s can be used for 11kV circuits but is likely to be pessimistic and provide onerous touch voltage limits.

   Alternatively the actual protection clearance time can be calculated (refer to EDS 06-0012 for calculation methods) and the circuit-breaker operating time of either 100ms (oil) or 50ms (SF₆ or vacuum).

   **Note:** For overhead line supplied substations it is permissible to use the pole-mounted recloser protection to achieve acceptable touch voltages provided there is sufficient backup from the source protection and/or chipping/concrete/tarmac surface covering is installed.

2. Calculate the touch voltage using the following formula:

   \[ V_{\text{Touch}} = \text{EPR} \times \%_{\text{Touch}} \]

   \[ V_{\text{Step}} = \text{EPR} \times \%_{\text{Step}} \]

   where \%_{\text{Touch}} and \%_{\text{Step}} are the percentage of the EPR at which the maximum touch and step voltage can occur.

   **Standard substation earthing arrangement touch and step percentage data** is available from EDS 06-0012 Appendix A. Otherwise they can be calculated using computer simulation software.

   **Note:** If the design does not use a UK Power Networks standard earthing arrangement then the earthing electrode system shall be modelled by an earthing specialist to determine the touch and step voltages.

3. Check whether the touch voltage \( V_{\text{Touch}} \) and step voltage \( V_{\text{Step}} \) is less than the acceptable limits \( V_{\text{TouchLimit}} \) and \( V_{\text{StepLimit}} \).

   **BS EN 50522 touch and step limits** are available from EDS 06-0012.
4. If the touch or step voltage exceeds the limits further work is required to reduce the substation resistance and the EPR. The value of $R_{SecSub}$ can be calculated using the equation below. However as the value of resistance changes the proportion of current returning through earth it will be necessary to repeat the steps in Section 7.3 to recalculate the EPR. It may be necessary to repeat this several times to determine actual values of resistance and EPR.

If the substation is supplied directly from the overhead line network additional precautions may be required (e.g. additional ring electrode and/or a 150mm concrete or tarmac surround) to achieve acceptable touch voltages.

$$R_{SecSub} = \frac{V_{TouchLimit}}{I_{gr}}$$

**Note 1:** A design cannot be accepted or approved if the touch and step voltages exceed the applicable limits.

**Note 2:** Tarmac should only be used as a last resort at outdoor substations i.e. padmount or timber fence installations to achieve compliance due to the ongoing maintenance requirements.

5. Using the results of the calculations above determine the additional earth electrode (conductor, rods etc.) requirements using Appendix B.
7.6 Combined HV/LV Earths and Network Contribution

If the EPR value is less than 430V the HV and LV earths may be combined, however to achieve this it may be necessary to further reduce the overall earth resistance of the substation.

An underground cable network consisting of interconnected substations and metallic sheath cables can provide a low earth resistance that will be in parallel with resistance of the installed earthing system. Provided the substation earth resistance is below 10 ohms and the touch and step voltages are within the applicable limits the network contribution may be used to achieve a low overall earth resistance and an EPR value below 430V to allow the HV and LV earths to be combined.

A conservative contribution can be determined through inspection of the network to understand the number of interconnected substations and the lengths/types of cable. Alternatively, measurements or engineering experience can be used to determine a more accurate value.

**Network contribution assessment methods and supporting data** is available from EDS 06-0012 Appendix G.

The EPR can be recalculated as follows:

1. Assess the network contribution through inspection or measurement.

2. Recalculate the EPR using the substation earth resistance in parallel with the network earth resistance ($R_{SecSub} // R_{Network}$):

$$R_b = R_{SecSub} // R_{Network}$$

$$EPR = I_{gr} \times R_b$$

If it is not considered practical to achieve a low enough earth resistance to limit the EPR to 430V:

- The design shall be based on reasonably practical installation with an earth resistance to ensure the EPR is below 2kV.
- Separate HV and LV earths shall be installed.
- The extent of the 430V zone and its impact on other LV electrodes and properties shall be evaluated.
- The site shall be classified as HOT (refer to Section 7.8).

In integral and basement substations the resistance contribution from vertical steel piles may also be used to supplement the main earthing system provided they are installed in accordance with Section 10.4. The resistance of the vertical piles is included in the calculations in a similar way to the Network Contribution above.

**Note 1:** If the LV supply is only supplying the substation the HV and LV earths shall always be combined.

**Note 2:** Further design work may be required if HV/LV earth segregation is not possible due to presence of HV/LV PILC cables.
### 7.7 Transfer Voltage Calculation

If the secondary substation is supplied from a source substation where the EPR is greater than 430V (or 650V for high reliability protection) it is necessary to calculate the transfer voltage (EPR\(_{\text{Transfer}}\)) from the source substation, if the secondary substation is:

- Entirely cable fed from a source substation and;
- Either the first substation on the circuit or within 500m of the source substation. Any intermediate substations may be disregarded to simplify the calculations.

![Figure 7-2 – Transfer Voltage](image)

1. **Obtain the necessary cable data.**

   **Cable data** for the transfer voltage calculation is available from EDS 06-0012 Appendix I.

2. **Calculate the transfer voltage using the following formula.**

   \[
   \text{EPR}_{\text{Transfer}} = \text{EPR}_{\text{Source}} \times \left(\frac{Z_B}{Z_{\text{Circuit}} + Z_B}\right)
   \]

3. If the transfer voltage is greater than 430V separate HV and LV earths shall be installed.

### 7.8 HOT Site Assessment

If the EPR is greater than 430V the secondary substation shall be classified as a HOT site.

The HOT/COLD site classification is mainly applicable to third party infrastructure, refer to EDS 06-0012 for further information.

The details of any HOT site shall be sent to UK Power Networks Asset Management (earthingenquiries@ukpowernetworks.co.uk) so that they can be recorded in the asset register. Openreach (or another telecommunication company) may also need to be notified (refer to Section 11.10 further details).
7.9 Electrode Surface Area Current Density Calculation

The surface area of the earth electrode in contact with the ground should be sufficient to pass the fault current without the ground around the electrode drying out and increasing in resistance.

The standard earthing arrangements when used with the criteria detailed in this standard generally satisfy the minimum surface area requirements and therefore detailed calculations for each project are not required. However where vertical piles are used to supplement the earthing system and the installed electrode is minimal the surface area calculations shall be carried out.

**Note:** The surface area of the piles or rebar shall not be considered as electrode in these calculations as excessive current flow into these structures can result in structural damage unless they have been specifically designed as earthing piles (refer to Section 10.4).

The Electrode Surface Area Current Density can be calculated using the formulae given in EDS 06-0012 Appendix H.
8 Standard Earthing Arrangements

8.1 Overview

This section details the earthing arrangements for the standard secondary substation designs. The arrangements include HV and LV (if required) earthing for the following types of ground-mounted substation:

- New COLD site design for GRP, brick-built and outdoor substations (Section 8.2).
- New HOT site design for GRP brick-built and outdoor substations (Section 8.2).
- Compact or micro pad-mount substations without an enclosure (Section 8.3).
- Integral and basement substations (Section 8.4).
- Customer substations (Sections 8.5).
- Existing outdoor substations (Section 8.6).

The earthing arrangements have been incorporated into the standard substation design drawings contained in EDS 07-3102.

**Standard substation earthing arrangement earth resistance data** is available from EDS 06-0012 Appendix A together with a full list of EDS 07-3102 earthing drawings.

**Note:** Plots showing the touch and step voltages across the substations with standard earthing arrangements are included in Appendix G.
8.2 GRP and Brick-Built Substations

The general earthing arrangement for GRP, brick-built and outdoor substations with a combined HV/LV earth (COLD site) is shown in Figure 8-1 and with separate HV/LV earths (HOT site) in Figure 8-1. Refer to EDS 07-3102 for specific designs.

![Diagram of earthing arrangement](image)

### HV Earth Electrode

<table>
<thead>
<tr>
<th>Primary Fault Level</th>
<th>Bare Copper Conductor</th>
<th>Bare Copper Tape</th>
<th>LV Earth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 8kA</td>
<td>70mm²</td>
<td>25mm x 3mm</td>
<td>n/a</td>
</tr>
<tr>
<td>Up to 12kA</td>
<td>120mm² (or 2 x 70mm²)</td>
<td>25mm x 4mm</td>
<td>n/a</td>
</tr>
<tr>
<td>Up to 15kA</td>
<td>2 x 70mm²</td>
<td>25mm x 6mm</td>
<td></td>
</tr>
</tbody>
</table>

1 - 2.4m earth rods at rear corners
2 - Alternative internal 2.4m earth rods in place of external ones for brick-built substations
3 - Perimeter earth electrode around the outer edge of foundation buried at a depth of 500-600mm
4 - Earth electrode connecting each side of outer loop to main earth terminal
5 - Connection to reinforcement rebar/mesh
6 - Equipment bonding
7 - Earth bar (perimeter earth ring connections adjacent to each other allow clamp meter measurements)
8 - Neutral/Earth link in place

**Note:** Only main equipment bonding is shown

---

7 Outdoor secondary substations are not generally used for new build, however they may be used in specific situations, e.g. Areas of Outstanding Natural Beauty, when GRP and brick-built designs are not suitable.
LV CNE Cable
LV earth connection – 70mm$^2$ PVC covered stranded copper conductor
HV/LV Separation (8m minimum)
LV Earth Electrode/Rods (max resistance 20Ω)

Table: HV Earth Electrode and LV Earth

<table>
<thead>
<tr>
<th>Primary Fault Level</th>
<th>Bare Copper Conductor</th>
<th>Bare Copper Tape</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 8kA</td>
<td>70mm$^2$</td>
<td>25mm x 3mm</td>
</tr>
<tr>
<td>Up to 12kA</td>
<td>120mm$^2$ (or 2 x 70mm$^2$)</td>
<td>25mm x 4mm</td>
</tr>
<tr>
<td>Up to 15kA</td>
<td>2 x 70mm$^2$</td>
<td>25mm x 6mm</td>
</tr>
</tbody>
</table>

LV Earth
- LV connection – 70mm$^2$ PVC covered stranded copper conductor
- LV earth electrode – 70mm$^2$ bare stranded copper conductor

1 - 2.4m earth rods at rear corners
2 - Alternative internal 2.4m earth rods in place of external ones for brick-built substations
3 - Perimeter earth electrode around the outer edge of foundation buried at a depth of 500-600mm
4 - Earth electrode connecting each side of outer loop to main earth terminal
5 - Connection to reinforcement rebar/mesh
6 - Equipment bonding
7 - Earth bar (perimeter earth ring connections adjacent to each other allow clamp meter measurements)
8 - Neutral/Earth link removed
9 - Warning labels

Figure 8-2 – GRP or Brick-built Substation Earthing Arrangement for a HOT Site
8.3 Padmount (including Micro and Compact) Substations

The earthing arrangement for a compact/micro substation without an enclosure is shown below. These are generally installed on the overhead network and therefore the HV and LV earths shall be separated. However if the EPR is less than 430V, the HV and LV earths may be combined. Both arrangements are shown in Figure 8-3.

Refer to EDS 07-3102 for specific designs.

Note: If the compact substation is installed in a GRP enclosure the standard arrangements shown in Section 8.2 shall be used.

---

**Figure 8-3 – Padmount Substation Earthing Arrangement**
8.4 Integral, Basement and Raft Substations

The standard arrangements shown Section 8.2 should be used wherever possible. However where the substation is situated within a building or on a raft, it is usually impracticable to install one of these arrangements. In these situations a standard approach shall be applied using earth rods installed through the substation floor or in the basement, external electrodes underneath the HV cable, vertical piles and an embedded mesh within the floor screed (to control the touch and step voltages).

It is not usually possible to separate the HV and LV earths, so it is important to achieve an EPR value of less than 430V (COLD site) so that they can be combined. If the EPR is greater than 430V or if the building or its electrical supply will interact with Network Rail, London Underground or other electrified travel infrastructure, a bespoke design is necessary, involving an earthing specialist.

The earthing design should include the following elements which are illustrated in Figure 8-4 (a):

- 2 to 4 vertical earth rods through the substation floor (Figure 8-4 (b)) or the basement (Figure 8-4 (c)) directly into natural soil, to achieve a sufficiently low earth resistance for a low EPR.
- Alternatively dedicated vertical earthing piles may be used in place of earth rods (refer to Sections 7.3 and 10.4).
- An embedded mesh in a thin layer of concrete (Figure 8-4 (d)) to control the touch voltages around the equipment.

The following options, where practical, may be used to supplement the above:

- Install at least 20-50m of bare copper electrode underneath the HV cable, directly into natural soil.
- Install bare copper electrode in the soil at a depth of approximately 500mm, adjacent or up to 1m away from the outer walls of as many sides of the UK Power Networks part of the building as possible. Wherever practicable, this shall include the wall adjacent to the HV switchgear.
- Incorporate the earth contribution from vertical piles near the substation into the design (Sections 7.3 and 10.4).

The standard approach outlined above should cover the majority of integral, basement and raft substations; however advice from an earthing specialist should be sought at an early stage for more complex installations.

**Note:** Where the earth rods are installed in the basement, the connections between these and the substation shall be mechanically protected in either steel conduit or steel trunking. Additionally the basement area where the rods enter the natural soil shall be accessible to UK Power Networks for testing and maintenance purposes.
Figure 8-4 – Standard Design Approach for Integral and Basement Substation

1a - Main earth rods (length to be determined by calculation based on target resistance value and soil resistivity)
1b - Optional additional earth rods to help achieve overall low resistance
1c - Optional bare earth electrode laid with incoming HV cables to help achieve overall low resistance
2 - Connections to mesh embedded within concrete floor screed - two per each sheet of mesh
3 - Main earth bar
4 - Wall-mounted earth ring above floor level/below door tread to aid connections
5 - Main equipment bond (not all equipment shown)
6 - Doorframe and door bonding
8.5 Customer HV Supplies and Associated Substations

The earthing system for an HV supply and any associated customer substation will usually consist of parts provided by UK Power Networks and parts provided by the customer. The objective is to design an earthing system that satisfies the safety requirements with an acceptable degree of redundancy and, wherever possible, an EPR less than 430V to allow the customer to combine the HV and LV earths if required.

Note: UK Power Networks is not responsible for a HV customer's earthing arrangements but has a duty of care to ensure that the customer's system will not be dangerous in the event of a HV fault.

The UK Power Networks substation shall be designed in accordance with Section 7 using a suitable earthing arrangement from Section 8.

The customer substation will be subjected to the same network operating conditions as the UK Power Networks substation and therefore the customer substation earthing system should be designed, as a minimum, to control the touch and step voltages and ensure safety in and around their installation.

This approach should ensure that UK Power Networks and customer earthing systems are each adequate to ensure safety in the absence of the other system. The customer system shall not be reliant on UK Power Networks earth system for safety (and vice-versa) since the integrity of either system can be subject to external influences.

The HV cable screen should be bonded to both earthing systems to provide a return path for any fault current. The customer may rely upon the cable sheath connection for current return to source, i.e. they do not need to assume 100% ground return current.

Additionally if the UK Power Networks and customer substations are within 10 metres of each other the earthing systems should be combined via duplicate earth connections bolted onto the earth bar in each substation. Clear labelling shall be provided at both locations warning of earth system inter-connection. The connection points shall be clearly labelled and bolted to facilitate disconnection under controlled conditions should this be necessary.

In some situations, it may be necessary to rely on combined systems to ensure safety of both systems (i.e. where safety of each system in isolation cannot economically and/or practically be achieved). In such cases, the systems shall be combined as described above, and the customer substation earthing system shall be constructed to UK Power Networks standard (in terms of conductor sizing, method of installation and touch/step requirements). However care is needed if the customer system should become decommissioned or compromised.

Once independent safety is achieved the combined resistance of both earthing systems can be used to calculate the final EPR. If the EPR is below 430V the customer HV and LV earths can be combined and the site classified as COLD.

The situation is more complex if the EPR exceeds 430V and the site is classified as HOT. It may be possible to separate the customer HV and LV earthing systems at all points by a minimum of 8m and ensure that they cannot be interconnected but precautions may also be required to ensure that a person cannot contact both earth systems simultaneously. Therefore it is recommended that an earthing specialist is consulted to ensure the earthing arrangement is acceptable and satisfies the relevant safety criteria.

Examples for COLD and HOT sites are shown in Figure 8-5 and Figure 8-6.

Note: If the EPR is greater than 430V the transfer voltage requires special consideration especially if there are metallic boundary fences or metallic buildings in the vicinity.
Secondary Substation Earthing Design

1 - 2.4 m earth rods at 2 corners of substation (alternatively they can be installed internally)
2 - HV electrode around the outer edge of foundation buried at a depth of 500-600mm
3 - HV electrode connecting outer loop to earth bar
4 - Multiple connections to reinforcement rebar/mesh
5 - Connection between UK Power Networks and Customer substations if within 10 metres
6 - Neutral-earth link in place
7 - HV cable screen bonded to earth at both ends
8 - Warning labels

Figure 8-5 – Typical HV Supply and Customer Substation Arrangement for a COLD Site
HV/LV Separation (8m minimum)

LV Earth Cable (Insulated)

Customer LV SNE Cables

---

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.4 m earth rods at 2 corners of substation (alternatively they can be installed internally)</td>
</tr>
<tr>
<td>2</td>
<td>HV electrode around the outer edge of foundation buried at a depth of 500-600mm</td>
</tr>
<tr>
<td>3</td>
<td>HV electrode connecting outer loop to earth bar</td>
</tr>
<tr>
<td>4</td>
<td>Multiple connections to reinforcement rebar/mesh</td>
</tr>
<tr>
<td>5</td>
<td>Connection between UK Power Networks and Customer substations if within 10 metres</td>
</tr>
<tr>
<td>6</td>
<td>Neutral-earth link removed</td>
</tr>
<tr>
<td>7</td>
<td>HV cable screen bonded to earth at both ends</td>
</tr>
<tr>
<td>8</td>
<td>Warning labels</td>
</tr>
</tbody>
</table>

---

Figure 8-6 – Typical HV Supply and Customer Substation Arrangement for a HOT Site
8.6 **Outdoor Substations**

Outdoor (open compound) secondary substations are no longer constructed except in Areas of Outstanding Natural Beauty. For these a close boarded fence is required. Refer to EDS 07-3102 for specific designs.

9 **Existing Substation Earthing Assessment Procedure**

The earthing at all existing substations shall be reviewed during asset replacement or enhancement (e.g. supply upgrades) to ensure that it satisfies current earthing standards. However any earthing enhancement should be proportional to the actual work being carried out and be practical to install.

The flowchart in Figure 9-1 provides guidance on the application of this approach.

**Note:** Further work is being carried out into the provision of suitable and practical earthing systems for existing substations and a further revision to this document will be published once complete.

The earthing system should be based around the design procedure in Section 7 using a standard arrangement from Section 8 but where this is not practical the earthing system should seek to achieve as much of the following as possible, using the excavations available for the remedial work:

- Buried bare electrode around the equipment at a depth of around 0.5m and connected to the main earth bar. It is especially important to ensure that there is bare electrode under the operator’s standing position – particularly if metallic sheathed cables have been removed or disconnected in this area.
- Short lengths of buried earth electrode where metallic sheathed cables are replaced with plastic cables during a switchgear change.
- A grate or mesh under the operator’s standing position if buried electrode is not practical.
- An embedded and bonded mesh (brick-built, integral and basement type substations).
- One or two earth rods connected to the buried earth electrode or the main earth bar.
- Bonding of all equipment to the main earth bar.
- Appropriate bonding and/or earthing of any metallic fence or gate.

Some examples are shown in Figure 9-2.
Asset replacement or reinforcement?
Yes

Yes
Carry out earthing design using earthing tool

Enhance existing earthing arrangement to replicate design

No
Excavation around switchgear?
Yes
Install buried grading electrode around equipment and under operator position

Ensure all new and existing equipment is bonded to a common earth terminal

Yes
Cut through switchgear

No
Lay new earth electrode

LV to HV/LV substation conversion?
Yes

Overall earth resistance <10 ohms?
No

Yes
Cable fed or connected to large* cable network?

No
Install embedded mesh or grate in front of switchgear

LV to HV/LV substation conversion?
Yes

Implement agreed design

No
Discuss options with designer/planner

Earthing arrangement matches design?
Yes

Yes
Install earth electrode with cable

Ensure fence is earthed and bonded in accordance with the earthing standards

No
Check existing earthing and measure resistance of earth rods using clamp meter

No
Excavation with cable?

No
Measure earth resistance

Earthing resistance less than design value?
Yes

No
Install additional earthing to reduce resistance

Ensure fence is earthed and bonded in accordance with the earthing standards

*Minimum of 5 connected substations and 1000m of PILC cable or a minimum of 10 connected substations

Figure 9-1 – Existing Substation Earthing Assessment Flowchart
Figure 9-2 – Typical Existing Substation Earthing Options

- **(a)** Equipment Replacement Only
- **(b)** Transformer Upgrade
- **(c)** Switchgear Replacement Only
- **(d)** Switchgear Replacement Only - Steel Grate or Mesh
- **(e)** New Switchgear/Transformer - Ring Electrode
- **(f)** New Switchgear/Transformer – Embedded Mesh

- Earth rods
- Buried bare copper earth electrode ring around the equipment
- Buried bare copper earth electrode in front of the switchgear where an operator stands
- Wall mounted earth bar
- Embedded mesh
- Connection to earth terminal

- Steel Grate

- Embedded Mesh within Floor Screed
10 Installation Requirements

This section details the general earthing requirements for all new and modified earthing installations.

- If combined HV/LV earthing is installed then the requirements in Sections 10.1 to 10.7 shall apply. The HV and LV earthing should be bonded together as described in Section 10.7.
- If it has been determined that separated HV and LV earthing is to be installed then the requirements of Section 10.8 shall also apply in addition to Section 10.1 to 10.6.

10.1 General

The theft of copper earthing has been a significant nationwide problem. Therefore the earthing system shall be designed and constructed to ensure that it is secure and not vulnerable to theft. To aid this aluminium conductor or tape shall be used for all above ground earthing wherever appropriate and practicable.

10.2 Electrode System

The earth electrode system shall provide the basic functional earthing for the site so that it is SAFE without any contribution from the network to which it is to be connected. The earth electrode system shall therefore consist of the following:

- Bare copper clad earth rod electrodes using the minimum sizes specified in Table 10-1. Dedicated earthing piles may also be used (refer to Section 10.4).
- A ring of bare earth electrode buried around the perimeter of the substation at a depth of 500-600mm.
- Alternatively where it is not practical to install a buried perimeter electrode (e.g. integral and basement substations) an embedded mesh within the floor screed may be used.
- A minimum of two earth rods installed on two corners of the substation (or alternatively internally) and connected to the perimeter ring.
- Two connections from the perimeter earth ring (or each embedded mesh) onto a dedicated substation earth bar.
- An earth electrode passing underneath any switchgear or LV operating position and connected to the outer electrode. This may be omitted if it can be shown that rebar (or equivalent) or an insulated or earthed operator platform is providing this function.
- Connections to the rebar or reinforcement mesh. The rebar shall not extend where it might be within 2m of LV metalwork or other earthed metalwork if the substation is HOT.
- Additional electrode and rods, as necessary, to achieve the required earth resistance.

Table 10-1 – Earth Electrodes

<table>
<thead>
<tr>
<th>Function</th>
<th>Source Fault Level</th>
<th>Bare Copper Stranded Conductor</th>
<th>Bare Copper Tape</th>
</tr>
</thead>
<tbody>
<tr>
<td>HV Earth Electrode</td>
<td>Up to 8kA</td>
<td>70mm²</td>
<td>25mm x 3mm</td>
</tr>
<tr>
<td></td>
<td>Up to 12kA</td>
<td>120mm² (or 2 x 70mm²)</td>
<td>25mm x 4mm</td>
</tr>
<tr>
<td></td>
<td>Up to 15kA</td>
<td>2 x 70mm²</td>
<td>25mm x 6mm</td>
</tr>
</tbody>
</table>
| Earth Rod Electrode| Any               | 1m or 1.2m Copper Clad Rods (16mm or 19mm diameter) |}

9 The earth fault level at the grid or primary substation supplying the secondary substation.
10.3 Earth Bar

All earth connections shall be labelled and connected via separate connections to a dedicated earth bar (GRP/brick-built designs) or marshalling bar or tape (integral/basement designs) which in turn shall be connected to the main transformer-switchgear earthing terminal to allow:

- Operational personnel to determine if the earthing is intact when entering the substation.
- The earthing to be easily identified.
- The earth resistance to be measured using a clamp meter.

**Note:** At new enclosed substations the HV earth bar within the LV cabinet/pillar shall not be used to marshal the earthing connections as access, particularly at IDNO substations, to the LV cabinet/pillar is not always available. However it is acceptable to use the HV earth bar within the LV cabinet/pillar at existing outdoor sites for all earth connections to prevent theft.

10.4 Earth Piles

Dedicated vertical foundation piles which have been specifically selected or designed for earthing may be used as earth electrode instead of earth rods.

Standard vertical piles are generally not suitable for use as dedicated earth electrodes but they may be used to supplement the installed electrode system provided the surface area current density requirements (Section 7.9) have first been satisfied by the installation of dedicated copper rods/electrode.

High current may flow through the piles during an earth fault therefore the use of piles for earthing shall be agreed with UK Power Networks. The developer/customer is responsible for providing suitable connection points to the piles and shall accept full liability for their use within the earthing system. A typical arrangement is shown in Figure 10-1.

The piles shall be connected as detailed in ECS 06-0022 which includes sample drawings.
10.5 Bonding

10.5.1 Equipment Bonding

All current carrying items of equipment including the switchgear, LV pillar/cabinet/board and ACB shall be bonded to the transformer (or switchgear) earth terminal using an independent connection. The minimum size of the bonding conductors is detailed in Table 10-2.

All other non-current carrying items of equipment (e.g. control units, RTUs, battery chargers etc.) shall be bonded to the main earth terminal using a minimum of 35mm$^2$ covered aluminium cable, 16mm$^2$ covered stranded copper cable or equivalent$^{10}$.

Table 10-2 – Bonding Conductors

<table>
<thead>
<tr>
<th>Function</th>
<th>Source Fault Level</th>
<th>Covered Stranded Cable</th>
<th>Tape</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below Ground Electrode or Above Ground Bonding</td>
<td>Up to 8kA</td>
<td>70mm$^2$ Copper</td>
<td>25mm x 3mm Copper</td>
</tr>
<tr>
<td></td>
<td>Up to 12kA</td>
<td>120mm$^2$ (or 2 x 70mm$^2$) Copper</td>
<td>25mm x 4mm Copper</td>
</tr>
<tr>
<td></td>
<td>Up to 15kA</td>
<td>2 x 70mm$^2$ Copper</td>
<td>25mm x 6mm Copper</td>
</tr>
<tr>
<td>Above Ground Bonding</td>
<td>Up to 8kA</td>
<td>120mm$^2$ Aluminium</td>
<td>25mm x 6mm Aluminium</td>
</tr>
<tr>
<td></td>
<td>Up to 15kA</td>
<td>240mm$^2$ Aluminium</td>
<td>40mm x 6mm Aluminium</td>
</tr>
</tbody>
</table>

$^{10}$ Minimum conductor sizes based on BS EN 50522.
### 10.5.2 Metallic Fences, Gates and Doors

Metallic fences, gates and doors require special attention as they can be touched by both staff and public. The risks that need to be managed are the touch voltage for persons making contact inside or outside of the substation and hand-to-hand voltages between these items and the earthed substation equipment. Table 10-3 outlines the various options to reduce the risks for HOT and COLD sites.

Table 10-3 – Requirements for Earthing of Metallic Fences, Gates and Door

<table>
<thead>
<tr>
<th>Item</th>
<th>Action for COLD Site</th>
<th>Action for HOT Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal fence/gate within 2m of earthed substation equipment, including gates in the open or closed position</td>
<td>Bond to substation earthing system</td>
<td>Either: Install an insulating barrier to prevent simultaneous contact Or: Bond to substation earthing system and assess/control touch voltages outside of fence – see Section 10.5.2.1</td>
</tr>
<tr>
<td>Metal door/frame within 2m of earthed substation equipment, including door in the open or closed position</td>
<td>Bond to substation earthing system</td>
<td>Either: Install an insulating barrier to prevent simultaneous contact Or: Bond to substation earthing system and assess/control touch voltages outside door – see Section 10.5.2.3</td>
</tr>
<tr>
<td>Metal fence/gate greater than 2m from any earthed substation equipment, including door in the open or closed position</td>
<td>Bond to substation earthing system</td>
<td>Do not bond to earthed substation equipment. Apply separate earthing system – see Section 10.5.2.1</td>
</tr>
<tr>
<td>Metal door/frame greater than 2m from any earthed substation equipment, including door in the open or closed position</td>
<td>Bond to substation earthing system</td>
<td>Do not bond to earthed substation equipment. Apply separate earthing system – see Section 10.5.2.3</td>
</tr>
</tbody>
</table>
10.5.2.1 Metallic Fences and Gates

1. For all installations:
   - Each metallic gate shall be bonded to the gatepost using flexible 35mm² covered stranded aluminium cable or 16mm² covered stranded copper cable or tinned copper braid.
   - Each pair of gateposts shall be bonded together using flexible 35mm² covered stranded aluminium or 16mm² covered flexible stranded copper cable (unless the frame is a single piece ‘goalpost’ type arrangement).
   - An earth rod shall be installed either side of any overhead line crossing.

2. If a metallic fence is installed within 2m of accessible earthed equipment the following additional requirements apply:
   - The fence shall be connected to the HV earth.
   - At HOT sites, a grading electrode of 70mm² bare copper cable or 25mm x 4mm bare copper tape shall as a minimum be installed under the fence line, or just inside (or outside), ideally at a depth of 500mm (300mm minimum) and connected to the fence; this is to protect staff and the public from dangerous touch voltages. Ideally, and if practicable the grading electrode should be installed outside the fence at a distance of 300-500mm away from the fence (in some situations the designer will specify an outside grading electrode, in which case an electrode underneath or inside the fence line is unacceptable).

3. If a metallic fence is installed greater than 2m from accessible earthed equipment the following additional requirements apply:
   - At COLD Sites is shall be connected to the HV earth.
   - At HOT sites, it shall not be connected to the HV earth. Instead a single earth rod shall be installed at each corner fence/gate post (and every 5m at larger sites) and connected to the fence to eliminate stray voltages. These electrodes, and any fence foundations, should be kept clear of any buried metallic sheathed cables.

10.5.2.2 Third Party Metallic Fences

Third party metallic fences shall not be directly connected to the substation enclosure or fence and shall be segregated from any metalwork connected to the substation earth by a minimum of 2m. Where this is not possible an insulating or standoff fence panel shall be introduced into the fence line to maintain separation as detailed below:

- Any insulating panel inset into a fence-line shall be at least 2m long to prevent any individual bridging the panel and simultaneously touching two separate earthing systems.
- If a metallic panel is to be supported on stand-off insulators, the panel shall be at least 2m in length with insulators at both ends, to create a fully floating panel. It is not sufficient simply to insulate at one end as this will create a touch voltage risk between the two parts of the fence.
- Sections of fence which are intended to be separate from other sections shall not be inadvertently connected together via anti-climbing guards, barbed wire, or similar. Nor should they be earthed to security lights along the fence line.
10.5.2.3 Metallic Doors

1. For all installations:
   - Each metallic door shall be bonded to the framework using flexible 35mm$^2$ aluminium or 16mm$^2$ copper covered stranded cable or tinned copper braid.

2. If metallic doors are installed within 2m of equipment or other earthed metalwork the following additional requirements apply:
   - The door framework shall be bonded to the HV earth using 35mm$^2$ aluminium or 16mm$^2$ copper covered stranded cable.

At HOT sites:
   - A loop of 70mm$^2$ bare copper cable or 25mm x 3mm bare copper tape shall be installed directly under the door at a depth of 300mm to 500mm. If practicable it should be outside the door, 1m from the door front and 500mm beyond each door frame as shown below. Each end of the loop shall be connected to the existing HV electrode using bare copper conductor. The complete loop shall be covered with a 100mm of concrete to provide protection against damage or theft.
   - Alternatively, a steel or copper mesh may be installed in concrete at a depth of 200mm to 300mm, covering the same area as above.
   - If the area outside of the doors is tarmac the grading electrode may be omitted.

3. If metallic doors are installed greater than 2m from equipment or other earthed metalwork the following additional requirements will apply:
   - The door frame and doors shall not be connected to the HV earth.
   - A driven earth rod (1m minimum) shall be installed at each door hinge post and connected to the post to eliminate stray voltages. The rods shall be kept clear of any buried earthing or metallic sheathed cables.

10.5.2.4 Fence, Gate and Door Replacement

The requirements of the previous sections also apply to fence, gate and door replacement; however ECS 06-0023 provides a more practical approach that is more suited to replacement at existing substations.

Care should be exercised when replacing wooden fencing with a metallic type (e.g. Pallisade, Expamet, 358 etc.) since its bonding requirements are more onerous, and it is unlikely that a fence earthing system will exist. It is not sufficient simply to replace wooden panelling with metallic, nor is it sufficient to merely bond metallic fence panels together above ground without a buried electrode system.

Metallic fences even if painted or powder coated shall be considered as bare metal unless covered in an approved insulated coating that will not degrade over time.
10.5.3 Building Façade with Metallic Cladding or Panels

The earthing of metallic cladding or panels installed on a building façade requires careful consideration to ensure that a) a high EPR is not exported from the substation to larger area where public may be present and b) that metalwork connected to different earthing systems (i.e. building LV earth and substation HV earth) cannot be touched at the same time.

The risks and solutions are similar to fences, in that the earthing systems may be bonded together or segregated provided that appropriate precautions are taken to control voltage differences in the substation and around the building.

In most cases it will not be practical to isolate the cladding as typically it will be fixed to a metal substructure which is (deliberately or fortuitously) bonded to the LV earth. For a COLD substation with combined HV/LV earths this gives rise to an acceptable risk but for HOT sites, where the building structure/cladding is likely to be connected to the LV earth, special measures are needed to ensure that HV and LV earths remain safely separated.

There are several options available to achieve this and each situation needs to be individually assessed to determine the most appropriate solution.

1. Bond all building cladding/panels together, connect to the substation earthing system and install a grading electrode around the substation/building to control the touch voltage.

2. Bond the cladding/panels in immediate vicinity of substation to the substation earthing system (HV) and install a grading electrode in front of the substation doors and the bonded cladding/panels to control the touch voltage. Ensure there is a 2m separation or an insulating barrier between the bonded cladding/panels and any non-bonded cladding/panels.

3. Bond the cladding/panels to substation door frame and ensure the door frame and doors are not bonded to the substation earthing system. Ensure a 2m separation inside the substation between any equipment/metalwork bonded to the substation earthing system and substation doors (and building structure etc.). Install warning labels to advise of the non-standard bonding. If 2m is not possible, insulation/barriers may be considered.

Note: It is recommended that an earthing specialist is consulted on the most appropriate solution.
10.5.4 Ducting and Ventilation Shafts

Metallic ducts and ventilation shafts passing through indoor secondary substations provide an electrical path between the inside and outside of the substation. If they are bonded to the HV earth, they could transfer voltage outside the substation zone and may pose a risk to the general public. Generally it is impractical to install measures to control touch and step voltages where these vents emerge.

Therefore one of the following approaches, in order of preference\(^{12}\), shall be taken to minimise risk to the public:

- Bond the ducts and ventilation shafts to the HV earth (unless the site is HOT), and install them such that they are out of reach where they emerge from the substation. To achieve this they shall be higher than 3m above ground or other foothold.
- Leave the ducts and ventilation shafts un-bonded, and install them such that there is no possibility of other metalwork (e.g. opening doors) making contact with the ducts or vents and no possibility of a simultaneous touch contact between the ducts and the HV equipment that is normally operated. As a further precaution a warning label can be installed.
- Use insulated ducts.

10.5.5 Pipework and other Metalwork

The substation and its associated earthing system shall be segregated from all metal pipework above or below ground by a minimum of 2m unless it is bonded to the LV earth.

If the substation is classified as HOT refer to Section 10.8.

10.5.6 Ancillary Metalwork

At COLD sites, all other exposed and normally un-energised metalwork inside the substation perimeter (e.g. ventilation ducts, staircases etc.) within 2m of other earthed metalwork shall be bonded to the main earth using 16mm\(^2\) covered copper cable or equivalent to avoid any voltage differences between different items of metalwork\(^{13}\).

At HOT sites, all such metalwork shall be bonded in the same way, except if the metalwork might give rise to risk outside the substation, in which case the advice of an earthing specialist shall be sought. Often the decision on whether to bond, or otherwise, needs to be backed up by appropriate risk assessment. See also the guidance for ventilation shafts below.

**Note:** Metal frames and other metallic parts that form part of a GRP enclosure or that support a GRP grating are excluded and may be left un-bonded.

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\(^{12}\) The risk to the public can be reduced by leaving the ducts and ventilation shafts un-bonded. However this may introduce a touch voltage risk to staff inside the substation since the ducts and vents may act as a remote earth and will therefore be at a different voltage to HV earth during fault conditions; the risk is the occurrence of an HV fault while staff are on site and bridging a gap between the HV earth and the duct. This risk is thought to be extremely small and is outweighed by the risk to public which may occur if the systems are bonded. It is likely that duct fans etc. or other fortuitous contact will provide connection to the LV earth in any case.

\(^{13}\) Minimum conductor sizes based on BS EN 50522.
10.6 Cables

All HV cable earth screens shall be bonded to the transformer or switchgear earth terminal.

All LV cables shall be bonded as follows:

- **CNE cables** - the outer sheath of the cable shall be connected to the neutral bar in the LV pillar/cabinet in accordance with Section 4 of the LV Cable Jointing manual.
- **SNE cables** - the outer sheath and armouring shall be bonded together and connected to the neutral bar in the LV pillar/cabinet/board. The neutral conductor shall be connected to the neutral bar in the LV pillar/cabinet/board in accordance with Section 4 of the LV Cable Jointing manual.

10.7 Combined HV/LV Earths

At COLD sites an LV electrode is not required. The LV neutral/earth link in the LV cabinet, pillar or board, that bonds the LV neutral/earth to the substation HV earth, shall be in place so that the HV and LV earths are combined.

10.8 Separate HV/LV Earths Additional Requirements

If the substation has an EPR greater than 430V it shall be classified as HOT and the additional requirements detailed in this section shall be applied where necessary.

Extra care is required to ensure that:

- All earthed metalwork is more than 2m from any other metalwork, pipework etc.
- Separate HV and LV earths are not inadvertently combined.
- Any additional PME earth electrodes are installed outside the 430V zone.
- All properties with LV supplies are outside the 430V zone.

10.8.1 LV Earth

A separated LV earth electrode shall be:

- Selected to provide a resistance of 20Ω or less.
- Separated from any HV electrode by at least 8m.
- Installed under an LV main cable in the cable trench wherever practicable to enhance its security.
- Connected to the neutral bar in the LV pillar/cabinet using 70mm² covered copper conductor (and laid under the LV cable) in accordance with the LV Cable Jointing manual.

If an existing substation with metallic sheathed HV and LV cables is being replaced with a new one it may not be possible to separate the HV and LV earths and further work is required to achieve an EPR below 430V to allow them to be combined.

10.8.2 Neutral-Earth Link

The HV/LV neutral-earth link shall be removed.

10.8.3 Warning Notices for Separated Earths

Where the HV and LV earths are separated, warning labels as detailed in ECS 06-0023 shall be installed next to the neutral-earth connection and on the site as required.
10.8.4 Lighting and Socket Supplies

Generally, at secondary substations classified as HOT, the HV and LV earths are separated; therefore, care is required when providing power and lighting supplies to ensure that an operator cannot touch metalwork connected to different earthing systems at the same time.

Therefore, at secondary substations classified as HOT:

- An isolation transformer with a minimum 5kV insulation rating shall be used to supply the consumer unit and used for lighting and RTU supplies only.
- Light switches and conduits shall preferably be plastic; metallic light switches and conduits shall not be installed within 2m of any metalwork bonded to the HV earth.
- All 13A sockets shall be disconnected or removed from LV fuse cabinets and LV pillars.

At padmount type secondary substations, it is not usually practical to carry out the above but as a minimum the socket shall be disconnected or isolated. If the padmount substation is installed in an enclosure, the enclosure power and lighting may also be omitted.

Refer to ECS 06-0023 for further information on the practicalities of carrying this out on site.

Note: The provision of LVAC supplies shall be in accordance with EDS 08-1112 and substation electrical services shall comply with EDS 07-1119.

10.8.5 Street Lighting Columns

New substations with separate HV and LV earths shall not be installed within 2m of street lighting columns or other street furniture. An 8m separation is also required between the street lamp column and the HV earthing system.

However where this is impractical the columns shall be earthed via a separate earth rod installed adjacent to the column and shall not use the neutral/earth of a PME service. This will usually necessitate the use of a RCD in the street columns/furniture to ensure adequate disconnection time for LV faults.
11 Special Situations

11.1 General

This section provides further details on specific earthing circumstances that may be encountered when designing secondary substation earthing.

- Substation refurbishment and asset replacement/enhancement (Section 11.2).
- Secondary substations associated with higher voltage substations (Section 11.3).
- Supplies to/from HOT sites (see Section 11.4 and 11.5).
- Substations near livestock/horses or other high risk locations e.g. outdoor swimming pools, showers, zoos, locations where footwear is not worn etc (Section 11.6).
- Supplies to mobile phone masts (Section 11.7).
- Substations located near tower lines (Section 11.8).
- Substations located near railways (Section 11.9).
- Substations located near telephone exchanges (Section 11.10).
- Substations located near pipelines (Section 11.11).
- Substations located near cathodic protection systems (Section 11.12).
- Substations located near fuel filling stations (Section 11.13).
- IDNO substations (Section 11.14).
- HV generator connections (Section 11.15).
- Customer’s lightning protection (Section 11.16).

11.2 Substation Refurbishment and Asset Replacement/Enhancement

When work is carried out at substations, e.g. civil refurbishment, asset replacement or enhancement, the earthing shall be reviewed, and brought in line with current requirements; however the earthing enhancement should be proportional to the work being carried out and be practical to install.

The earthing should, where possible, be based around the standard arrangements shown in Section 8 using the guidance in Section 9.

Metallic fences, gates and doors require particular attention to ensure that they are correctly bonded in accordance with Section 10.5.2.

11.3 Secondary Substations within Grid or Primary Substations

Generally where a secondary substation is located within the earthing system of a grid or primary substation a detailed earthing design is not required. A standard earthing arrangement should be used and be connected to the higher voltage substation earthing system via duplicate connections.

The standard earthing arrangements for new grid and primary substations detailed in EDS 06-0013 include a provision for a secondary substation.
11.4 Supplies to Higher Voltage (Grid and Primary) Substations, National Grid and HOT Sites

For supplies to HOT sites and all National Grid sites refer to EDS 08-2108 before carrying out the earthing design to determine a suitable supply and earthing arrangement.

Acceptable arrangements for supplies to COLD grid and primary substations are shown in Figure 11-1.

![Figure 11-1 – Options for Supplies to Higher Voltage Substations](image)

11.5 Supplies from Grid or Primary Substations with a High EPR

Supplies shall not be taken from a grid or primary substation with an EPR greater than 430V (or 650V for high reliability protection) without the approval of Asset Management. However Figure 11-2 shows an arrangement which may be used, with care, to provide an LV supply from a secondary substation provided the following criteria are satisfied:

- The EPR shall not exceed 2kV.
- The LV earth electrode shall be installed outside the 430V (or 650V) contour.
- The LV cable and LV earth cable shall have an insulated sheath and be installed in an insulated duct (both rated to withstand the maximum EPR of the site) inside the 430V (or 650V) contour. A 650V sheath withstand may be assumed for covered cables in the absence of manufacturer’s data.
- The screens/armours of all outgoing LV cables shall be isolated from the substation metalwork.
- Any outgoing LV metallic sheathed/armoured cables shall be replaced with a cable with an insulated sheath for the length of their passage through the 430V (or 650V) contour.
- Appropriate labelling shall be applied. Refer to EDS 08-2108 for examples.
11.6 Substations near Livestock/Horses or other High Risk Locations

Substations near livestock/horses or other high risk locations e.g. outdoor swimming pools, showers, zoos, locations where footwear is not worn etc. shall be avoided if possible.

If unavoidable, the electrode system shall be located away from where humans and animals are likely to be and shall be installed at a minimum depth of 1m and separated from any of the above by a minimum of 1m.

For situations where electrode is already installed in these areas, or where such areas are unavoidable, an earthing specialist should be employed to carry out computer modelling to calculate the step voltages and the results used to determine suitable mitigation strategy. The target voltage gradient in soil should not exceed 25V/m\(^{14}\).

11.7 Mobile Phone Base Stations Associated with Transmission Towers

For supplies to mobile phone base stations mounted on 132kV, 275kV or 400kV transmission towers refer to EDS 08-2109 before carrying out the earthing design.

11.8 Substations Located Near Tower Lines

Secondary substations shall, where possible, not be situated within 50m of a 400kV, 275kV or 132kV tower. However if the substation is situated within 50m of a tower the earthing system requires special consideration and an earthing specialist should be employed to calculate the transfer voltage from the tower line.

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\(^{14}\) Animals are particularly susceptible to voltage gradients in soil and ENA 41-24 Issue 2 suggests that voltage gradients (e.g. around remote electrodes or structures placed in fields) not exceeding 25V/m will generally not result in animal fatality.
11.9 Substations Located Near Railways

Substations, and the associated power cables and earthing system, should ideally be segregated from railways by a minimum of 50m (DC railways) or 10m (AC railways).

If 50m is not practical for DC railways, a reduced 10m clearance is permissible provided that additional (sacrificial) electrode is installed to minimise the effects of DC erosion. One method is to double the rods and electrode that would normally be installed, accepting this will erode over time.

If it is not possible to satisfy the above requirements or there is any doubt an earthing specialist should be employed to carry out more detailed calculations and determine a suitable mitigation strategy to guard against export voltages or DC leakage.

For further information on LV supplies to railway installations refer to EDS 06-0017.

11.10 Substations Located Near Telephone Exchanges

If the substation is HOT and within 10m of a telephone exchange Openreach (or the appropriate telecommunication company) shall be informed and the appropriate information provided. For further guidance refer to EDS 06-0002 (internal) or ENA EREC S36 (external).

11.11 Substations Located near Pipelines

Substations, and the associated power cables and earthing system, should ideally be segregated from pipelines by a minimum of 50m in accordance with BS 50443:2011.

If this is not possible it will be necessary to employ an earthing specialist to carry out a detailed earthing study to:

- Calculate the voltage rise on the pipeline closest to the substation.
- Plot the voltage contours around the substation to determine the worst case voltage difference.
- Calculate the current density around the substation and the resultant current ‘collected’ by the pipeline.

These findings should be presented to the pipeline operator to allow them to decide if the voltage rise and collected current require any mitigation on their part.

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15 Source ENA EREC S36.
11.12 Substations Located near Cathodic Protection Systems

Cathodic protection systems use a DC voltage to reduce corrosion on the pipeline/structure. The method usually relies on rectifier units or buried sacrificial anodes to impress a voltage on the structure which causes DC current to return to a buried electrode(s) associated with the installation.

Substations or other metalwork close to this current path can provide a parallel (low impedance) return path for DC currents. Where such stray currents exit the substation earthing system they will cause erosion of the electrode.

Because the exact location of cathodic protection electrodes/rectifiers/anodes may be unknown, it is recommended that all substations are sited at least 50m from any plant or equipment connected to a cathodic protection installation.

Where this is not possible, a separation of 10m may be used, provided arrangements can be made to test the substation earthing system at yearly intervals. Alternatively, additional electrode should be installed (as for railway systems) to provide some sacrificial material. Despite this, simple non-intrusive testing may not reveal the loss of material below soil until the electrode system is so depleted as to require complete replacement.

Therefore advice from an earthing specialist should be sought for all substations within 50m of an installation with cathodic protection.

11.13 Substations Located near Fuel Filling Stations

Substations and the associated earthing system shall be segregated from a petrol or gas filling station LV earthing system by a minimum of 20m\(^{16}\) to avoid the transfer of voltage between the earthing systems.

Additional requirements relate to the provision of PME earthing to these installations (refer to EDS 06-0017).

These requirements also apply to other types of fuel storage e.g. oil or hydrogen. BS EN 60079 provides additional guidance for electrical installations within or close to potentially explosive atmospheres.

11.14 IDNO Substations

Independent Distribution Network Operator (IDNO) substations shall be designed to the standards detailed in this document and IDNOs shall be encouraged to use the standard arrangements and design a site with an EPR below 430V wherever possible.

UK Power Networks cannot insist on a particular value of EPR or whether combined/separated LV earth is used as UK Power Networks is not responsible for the substation or the LV network. However the substation shall be safe for UK Power Networks staff to enter and operate in and this shall be demonstrated in the design submission.

For further guidance on IDNOs and inset networks refer to EDS 08-1101.

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\(^{16}\) Based on BS EN 50522 Section 6.1.3.
11.15 HV Generator Connections (including Solar and Wind Farms)

Refer to EDS 06-0019 before carrying out the earthing design for substations associated with embedded or distributed generators.

The earthing system for a secondary substation for a HV generator connection shall be designed in accordance with this standard. The earthing system associated with the generator shall be designed in accordance with industry and national standards, however if the generator earthing system forms an integral part of the UK Power Networks’ substation earthing system it shall also be designed in accordance with this standard.

11.16 Customer’s Lightning Protection

Lightning protection is covered by BS EN 62305 (protection against lightning). BS EN 62305-3 specifies that the resistance of the lightning protection system (LPS) should not exceed 10Ω and that it is preferable to have a single integrated earthing system. Therefore provided the customer’s lightning system does not exceed 10Ω and the UK Power Networks earthing system EPR does not exceed 430V they should be connected together at the substation earth bar. The connection point shall be clearly labelled and bolted to facilitate disconnection under controlled conditions in the future should this be necessary.

The LPS will contribute to the overall earthing system but should not be relied upon, therefore the UK Power Networks earthing system shall be designed to operate safely without this contribution.

Note:
- There will be an electric shock risk between the two earthing systems if the connection between them is broken.
- If the two earthing systems are not bonded then care is required to ensure that metalwork connected to the two earthing systems cannot be touched simultaneously.
- If the two earthing systems are not bonded then during lightning strike conditions a flashover may occur between the lightning conductors and any pipework or conductor (including cables within the customer’s installation) connected to the earth terminal.
12 Earthing Design Assessment

12.1 External Connection Providers

12.1.1 Overview

External connection providers shall provide an earthing arrangement drawing and supporting earthing design report as detailed in Sections 12.1.2 and 12.1.3 to enable UK Power Networks to assess the secondary substation earthing design.

Earthing designs that do not include sufficient information or that do not meet the minimum requirements specified in this standard may be unsafe and shall not be granted design approval.

12.1.2 Earthing Drawing

An earthing arrangement drawing shall include as a minimum:

- Substation layout with earthing arrangement.
- Main earth electrode(s) and depth.
- Additional earth electrode required to obtain the earth resistance value.
- Earth rods.
- Rebar/reinforcement connections.
- All bonding to equipment, metalwork etc.
- Type and sizes of earth electrode, earth rods, bonding conductors etc.
- Warning labels.
- Site boundary and the position of any metallic fencing, street furniture or other metallic buildings or structures.

12.1.3 Earthing Report

The earthing design report (refer to Appendix F for example) shall include as a minimum:

- Base data and source.
- Value of required earth resistance.
- Ground return current.
- Earth potential rise (EPR) calculations.
- Touch and step voltage calculations and/or supporting voltage contour plots.
- Transfer voltage calculations if relevant.
- Details of any additional precautions that are required.

12.1.4 Further Information

For further information on earthing design refer to the following national standards: ENA TS 41-24, ENA EREC S34 and BS EN 50522.

12.2 UK Power Networks

A form to assist UK Power Networks designers with the assessment of a secondary substation earthing design is included in Appendix D.
13 References

13.1 UK Power Networks Standards

EDS 06-0001  Earthing Standard
EDS 06-0002  HOT Site Management (internal document only)
EDS 06-0012  Earthing Design Criteria, Data and Calculations
EDS 06-0013  Grid and Primary Substation Earthing Design
EDS 06-0015  Pole-mounted Equipment Earthing Design
EDS 06-0016  LV Network Earthing Design
EDS 06-0017  Customer LV Installation Earthing Design
EDS 06-0018  NetMap Earthing Maps (internal document only)
EDS 06-0019  Customer EHV and HV Connections (including Generation) Earthing Design and Construction Guidelines
ECS 06-0022  Grid and Primary Substation Earthing Construction
ECS 06-0023  Secondary Distribution Network Earthing Construction
EDS 07-1119  Substation Electrical Services
EDS 07-3102  Secondary Substation Civil Design Standards
EDS 08-1101  Guidance for the Application of ENA Engineering Recommendation G88 and G81 Inset Networks (IDNO's and other licenced DNO's)
EDS 08-1112  Substation LVAC Supplies
EDS 08-2108  Supplies to HOT Sites and National Grid Sites
EDS 08-2109  LV supplies to Mobile Phone Base Stations Mounted on 132, 275 and 400kV Towers (internal document only)

13.2 National and Industry Standards

ENA EREC G12  Requirements for the Application of Protective Multiple Earthing to Low Voltage Networks
ENA EREC G78  Recommendations for Low Voltage Supplies to Mobile Phone Base Stations with Antennae on High Voltage Structures
ENA EREC S34  A Guide for Assessing the Rise of Earth Potential at Substation Sites
ENA EREC S36  Procedure to Identify and Record HOT Substations
BS EN 50522  Earthing of Power Installations Exceeding 1kV AC
BS EN 62305  Protection against Lightning
BS EN 60079  Explosive Atmospheres

14 Dependent Documents

EOS 04-0035  Compact Substations
EDS 06-0001  Earthing Standard
EDS 06-0002  HOT Site Requirements (internal document only)
EDS 06-0012  Earthing Design Criteria, Data and Calculations
EDS 06-0013  Grid and Primary Substation Earthing Design
EDS 06-0015  Pole-mounted Equipment Earthing Design
EDS 06-0016  LV Network Earthing Design
EDS 06-0017  Customer LV Installation Earthing Design
EDS 06-0018  NetMap Earthing Maps (internal document only)
EDS 06-0019  Customer EHV and HV Connections (including Generation) Earthing Design and Construction Guidelines
ECS 06-0023  Secondary Distribution Network Earthing Construction
EDS 07-3102  Secondary Substation Civil Design Standard
EDS 08-0148  Appendices to ENA ER G81
EDS 08-1112  Substation LVAC Supplies
EDS 08-2108  Supplies to HOT Sites and National Grid Sites
EDS 08-3100  HV Customer Demand and Generation Supplies
Appendix A – UK Power Networks Supporting Data

The data required to carry out the earthing design for secondary substations detailed in this document is available from the Substation Earthing Design Tool. With the exception of soil resistivity this information is also available to external connection providers via the Substation Earthing Design Tool or their UK Power Networks nominated contact.

Table A-1 lists the original data sources.

Table A-1 – Data Sources for Earthing Design Calculations

<table>
<thead>
<tr>
<th>Data</th>
<th>UK Power Networks Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source substation earth fault current</td>
<td>DigSilent PowerFactory</td>
</tr>
<tr>
<td>Secondary substation earth fault current</td>
<td>Relevant HV/LV network modelling tool</td>
</tr>
<tr>
<td>Source substation earth resistance</td>
<td>Asset Register (refer to EDS 06-0001) or use 0.1Ω if no measured value available</td>
</tr>
<tr>
<td>Source substation classification (HOT or COLD)</td>
<td>Asset Register (refer to EDS 06-0001)</td>
</tr>
<tr>
<td>Circuit details</td>
<td>NetMap, GROND, DPlan</td>
</tr>
<tr>
<td>Source protection details</td>
<td>Asset Register</td>
</tr>
<tr>
<td>Secondary substation standard earthing arrangements</td>
<td>EDS 06-0012 Appendix A</td>
</tr>
<tr>
<td>Secondary substation soil resistivity</td>
<td>NetMap (refer to EDS 06-0018)</td>
</tr>
</tbody>
</table>
Appendix B – Typical Electrode Systems

Table B-1 shows various options for achieving HV and LV earth resistance values. Table B-2 and Table B-3 include the resistance of various lengths of earth rod, earth conductor and a lattice earth mat in different soil resistivity.

**Note:** NetMap also contains earthing maps showing the earthing requirements to achieve 0.5 Ω, 1Ω, 10Ω and 20Ω earths (refer to EDS 06-0018).

Table B-1 – 1Ω, 10Ω and 20Ω Earth Electrode Options

<table>
<thead>
<tr>
<th>Typical Soil Type/Soil Resistivity</th>
<th>1Ω Earth Resistance</th>
<th>10Ω Earth Resistance</th>
<th>20Ω Earth Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(a)</td>
<td>(b)</td>
<td>(a)</td>
</tr>
<tr>
<td>Loam 25Ωm</td>
<td>6 x 6m</td>
<td>11 x 2.4m</td>
<td>1 x 2.4m</td>
</tr>
<tr>
<td>Chalk 50Ωm</td>
<td>13 x 6m</td>
<td>27 x 2.4m</td>
<td>1 x 6.0m</td>
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<tr>
<td>Clay 100Ωm</td>
<td>34 x 4.8m</td>
<td>60 x 2.4m</td>
<td>3 x 4.8m</td>
</tr>
<tr>
<td>Sand, Gravel, Clay mix &lt;150Ωm</td>
<td>Site specific design required</td>
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<td>7 x 2.4m</td>
</tr>
<tr>
<td>Sand, Gravel, Clay mix &lt;200Ωm</td>
<td>Site specific design required</td>
<td>5 x 4.8m</td>
<td>9 x 2.4m</td>
</tr>
<tr>
<td>Sand, Gravel, Clay mix &gt;200Ωm</td>
<td>Site specific design required</td>
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<td></td>
</tr>
<tr>
<td>Slate, Shale, Rock 500Ωm</td>
<td>Site specific design required</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Column (a) denotes Deep-driven Vertical and Horizontal Electrodes**

Each deep-driven vertical electrode comprises of 1.2m rods coupled together to form the final vertical length e.g. 4.8m = 4 x 1.2m. Where there is more than one rod required, the spacing between them is 5m. The top of each electrode shall be at a minimum depth of 0.6m below ground level.

**Column (b) denotes Short Vertical and Horizontal Electrodes**

Each short-vertical electrode comprises of 1.2m rods coupled together to form the final vertical length e.g. 2.4m = 2 x 1.2m. Where there is more than 1 rod required, the spacing between them is 3m. The top of each electrode shall be at a minimum depth of 0.6m below ground level.

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25 To obtain the maximum effect from the rods the horizontal separation should be twice the length of the rod; however uniform distances are quoted to make installation easier.
### Table B-2 – Earth Rod Resistance based on Soil Resistivity

<table>
<thead>
<tr>
<th>No of Rods</th>
<th>Rod Length (m)</th>
<th>Resistance (Ω)²⁶</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>25Ωm</td>
</tr>
<tr>
<td>1</td>
<td>1.2</td>
<td>17.9</td>
</tr>
<tr>
<td>2</td>
<td>2.4</td>
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</table>

²⁶ Rod resistance calculated using formulae R1 from ENA EREC S34.

### Table B-3 – Earth Conductor and Lattice Earth Mat Resistance based on Soil Resistivity

<table>
<thead>
<tr>
<th>Conductor/Mat Length</th>
<th>Resistance (Ω)²⁷</th>
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<tbody>
<tr>
<td></td>
<td>25Ωm</td>
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<tr>
<td>Conductor</td>
<td></td>
</tr>
<tr>
<td>10m</td>
<td>3.6</td>
</tr>
<tr>
<td>25m</td>
<td>1.8</td>
</tr>
<tr>
<td>50m</td>
<td>1.0</td>
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<tr>
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<td>0.5</td>
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<tr>
<td>150m</td>
<td>0.4</td>
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<tr>
<td>200m</td>
<td>0.3</td>
</tr>
<tr>
<td>250m</td>
<td>0.2</td>
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<tr>
<td>1m x 1m Lattice Mat in Soil</td>
<td>13.2</td>
</tr>
<tr>
<td>1m x 1m Lattice Mat in Earthing Compound</td>
<td>3.7</td>
</tr>
</tbody>
</table>

²⁷ Conductor resistance calculated using formulae R7 from ENA EREC S34 and earth mat resistance calculated using formulae R4 from ENA EREC S34.
Appendix C – Earthing Design Form

Earthing data, design and construction forms (EDS 06-0014C) are available within the secondary substation earthing design tool.

The earthing design and construction forms should be completed by the designer/planning engineer and added to the work package with the appropriate EDS 07-3102 drawings.

Appendix D – Earthing Design Assessment Form

An earthing design assessment form is available as a separate document EDS 06-0014D.

Appendix E – Secondary Substation Earthing Design Tool

A secondary substation earthing design tool for use by UK Power Networks staff is available via Citrix.

The earthing design tool can be requested via MyIT > Do you want something? > Software Installs and Application Access > In-house Application Request. Type ‘substation’ into the search box, select ‘Substation Earthing Design Tool’ (as shown below) and complete the request in the usual way.

The earthing design tool is also available to ICPs; please the UK Power Networks Competition-in-Connections team for further information.

A user guide is available via the Help button in the earthing design tool.

Appendix F – Earthing Design Example

An earthing design example including the information required to demonstrate that a design is acceptable is available as a separate document EDS 06-0014F and may be used as a basis to formally submit designs for assessment.

Appendix G – Standard Secondary Substation Arrangement Voltage Profiles

The voltage profiles including the touch and step voltages for the standard substation earthing arrangements are available as a separate document EDS 06-0014G (internal document only).