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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:** 20/03/2023

Approved By: Paul Williams **Approved Date:** 09/05/2023

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Revision Record

Version	5.0	Review Date	20/03/2028
Date	20/03/2023	Author	Stephen Tucker

Reason for update: Full revision to ensure alignment with other earthing documents and incorporate learning and best practice from recent projects.

What has changed:

- Legacy content reduced and moved to footnote (Section 1).
- Scope clarified (Section 2).
- Design flowcharts updated (Section 6 & 7).
- Criteria for the combination of HV and LV earths changed to the touch voltage soil limit and F-factor (Section 7.6 and throughout document).
- Association between COLD/HOT classification and combined/separated HV/LV earths removed (throughout document).
- Transfer voltage assessment and reference to EDS 06-0002 included (Section 7.8).
- Standard earthing arrangement drawings updated (Section 8).
- Customer earthing guidance fully revised (Section 9).
- Existing substation earthing requirements updated (Section 10).
- 150mm^2 conductor included for fault levels up to 15kA in Table 11-1 and Table 11-2 (Section 11).
- Basement earth electrode criteria added (Section 11.4).
- Fence, door and building cladding bonding requirements revised (Sections 11.6).
- Third-party metallic fence guidance revised, and mitigation options included (Section 11.6.2.3).
- Customer cable section added (Section 11.7.2).
- Relevant voltage contour introduced in place of HOT zone (Section 11.9).
- LVAC supplies section added (Section 11.10).
- Substations near sensitive sites and animal guidance revised (Sections 12.6 & 12.7).
- Tower transfer voltage guidance added (Section 12.8).
- Substations associated with gas compressor stations and the use of stainless-steel earth rods added (Section 12.13).
- Substations near fuel filling station guidance revised (Section 12.14).
- Cable bridges added (Section 12.17).
- Earth conductor resistance values aligned to BS EN 50522 in Table B-3 (Appendix B).
- Earthing assessment form revised (EDS 06-0014D).
- Earthing design example updated (EDS 06-0014F).
- Standard earthing arrangement resistance and voltage contour data updated (EDS 06-0014G).
- Document reviewed.

Version	4.0	Review Date	23/11/2023
Date	09/11/2018	Author	Stephen Tucker

Reason for update: Full revision 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 11.5).
- 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 7.10).
- Further guidance on earthing at existing substations included (Section 10).
- GRP arrangements revised to align with EDS 07-3102 (Section 8).
- Customer supply arrangement revised (Section 8.6).
- Metalwork bonding requirements enhanced (Section 11.6).
- Revised guidance on substations near livestock, railways, cathodic protection systems, fuel filling stations and lightning protection systems included (Section 12).
- 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.

Version	3.0	Review Date	28/07/2019
Date	28/07/2014	Author	Stephen Tucker

Reason for update: Updated to ensure consistency with EDS 07-0102 and ECS 06-0023.

What has changed:

- 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 12.11) and fuel filling stations (Section 12.13) 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).

Version	2.0	Review Date	18/03/2018
Date	01/03/2013	Author	Stephen Tucker

Document completely revised.

Version	1.2	Review Date	28/07/2019
Date	03/08/2011	Author	Stephen Tucker

Reclassification of document from Earthing Design Manual Section 4.

Version	1.1	Review Date	31/12/2011
Date	11/01/2011	Author	Stephen Tucker

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

Version	1.0	Review Date	31/03/2011
Date	31/03/2008	Author	Stephen Tucker/ Rob Weller
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 industry and national standards.

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 a standard arrangement is not suitable.

This standard is based on the principles of ENA TS 41-24 and BS EN 50522 and supersedes all legacy[1] arrangements. The approach 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 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 to achieve the calculated earth resistance.
- The use of dedicated vertical piles (designed for earthing) in place of earth electrode and/or the use of standard vertical piles as supplementary earthing in addition to earth electrode.
- The contribution from the wider network to supplement the main earthing system if appropriate; however, the touch and step voltages shall be safe before any network contribution is considered.
- Additional precautions (e.g. additional ring electrode and/or a tarmac surround) to achieve acceptable touch and step voltages at substations supplied directly from an overhead line network.
- Conductor sizing based on a common approach to all three network areas.

Standard earthing arrangements based on the above requirements are included in the EDS 07-3102 and EDS 07-4055 suite of substation civil drawings.

[1] 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. This approach relied on metallic sheathed cables to provide 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. This approach does not comply with the requirements specified in the revised earthing standards ENA TS 41-24 and BS EN 50522 and is therefore no longer permitted.

2 Scope

This standard applies to the earthing design for:

- All new 20kV, 11kV and 6.6kV secondary substations.
- All new customer demand and generation connections at 20kV, 11kV and 6.6kV.
- All existing 20kV, 11kV and 6.6kV secondary substations where a material alteration is to take place, e.g. switchgear replacement, fencing replacement etc.

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

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

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 Glossary and Abbreviations

Term	Definition[2]
CDEGS	Current Distribution, Electromagnetic Fields, Grounding and Soil Structure Analysis. The CDEGS software package is a powerful set of integrated engineering software tools for modelling earthing systems
CNE	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
COLD Site	A COLD site is a substation where the earth potential rise is less than 430V or 650V (for high reliability protection with a fault clearance time less than 200ms)
EPR	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 network. **Note:** 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
Earth Conductor	An above ground conductor used to connect plant, equipment and electrodes of the earth electrode system
Earth Electrode	A conductor or group of conductors in direct contact with the soil, examples include rod, tape, cable steel, reinforcing bar etc.
Grid Substation	A substation with an operating voltage of 132kV or 66kV and may include transformation to 33kV, 22/20kV, 11kV or 6.6kV
GSA	UK Power Networks Geospatial Analytics application
High EPR	A high EPR site is typically where the EPR exceeds twice the touch voltage limit on soil (e.g. 466V for a fault clearance time of 1s) or the 1200V stress voltage limit whichever is the lowest
HOT Site	A HOT site is a substation where the earth potential rise is greater than 430V or 650V (for high reliability protection with a fault clearance time less than 200ms)
HV	High Voltage. Refers to voltages at 20kV, 11kV and 6.6kV
IDNO	Independent Distribution Network Operator
ITU	International Telecommunication Union. ITU directives prescribe the limits for induced or impressed voltages derived from HV supply networks on telecommunication equipment and are used to define the criteria for COLD and HOT sites
LV	Low Voltage. Refers to voltages up to 1000V AC (typically 400V 3-phase and 230V single-phase) and 1500V DC
NetMap	UK Power Networks graphical information system (GIS)
NER	Neutral Earthing Resistor. A method of system earthing used to reduce the earth fault current.
NEX	Neutral Earthing Reactor. A method of system earthing used to reduce the earth fault current.
PME	Protective Multiple Earthing. Refer to EDS 06-0017

[2] * Definition from BS EN 50522.

Term	Definition[2]
Primary Substation	A substation with an operating voltage of 33kV and may include transformation to 11kV, 6.6kV or LV
RCD	Residual Current Device
Relevant Voltage Contour	The voltage contour inside which additional precautions are required
Secondary Substation	A substation with an operating voltage of 20kV, 11kV or 6.6kV and may include transformation to 400V. Also termed 'Distribution Substation'
Source Substation	The grid or primary substation supplying the new substation or customer connection
SNE	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
SSEDT	Secondary Substation Earthing Design Tool
Step Voltage	The step voltage is the voltage difference between a person's feet assumed to be 1m apart. **Note:** In practice, in view of revised limits in BS EN 50522 and ENA TS 41-24, step voltage considerations are more of an issue for animal/livestock areas
Stress Voltage	The voltage appearing during earth fault conditions between an earthed part or enclosure of equipment or device and any other of its parts and which could affect its normal operation or safety. The stress voltage limit is 1200V from BS EN 50522
Touch Voltage	The touch voltage is the voltage difference between a person's hands and feet when standing up to 1m away from any earthed metalwork they are touching. **Note:** Hand-to-hand voltage differences within substations are generally not considered as they should be avoided by careful design
Transfer Voltage	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
TT	Terre-Terre. An LV earthing system where no network earth terminal is offered to the customer. Refer to EDS 06-0017
UK Power Networks	UK Power Networks (Operations) Ltd consists of three electricity distribution networks: • Eastern Power Networks plc (EPN). • London Power Network plc (LPN). • South Eastern Power Networks plc (SPN).

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, ENA TS-41-24, BS EN 50522 and BS 7430; and

c) ensure that the substation is safe to energise and operate.

5 Design Requirements

The substation earthing system 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 to all secondary substations:

- A maximum HV electrode earth resistance of 10Ω to operate the HV protection.
- A maximum earth potential rise of 2kV to avoid exceeding substation equipment stress voltage limits.
- 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.
- A low earth potential rise to allow the HV/LV earths to be combined.
- A maximum LV earth resistance of 20Ω (in accordance with ENA EREC G12) where separate HV and LV earths are required.
- The touch voltage within the acceptable limits using the substation standalone electrode system only[3]; the touch voltage calculation shall not rely on any parallel earth resistance contribution from the network.
- A practical earthing arrangement is proposed that can be installed on-site to avoid re-design at the time of installation.

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

[3] This should ensure that the touch and step voltages within and around the substation are safe for the design life of the substation, and help to mitigate the impact of 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.

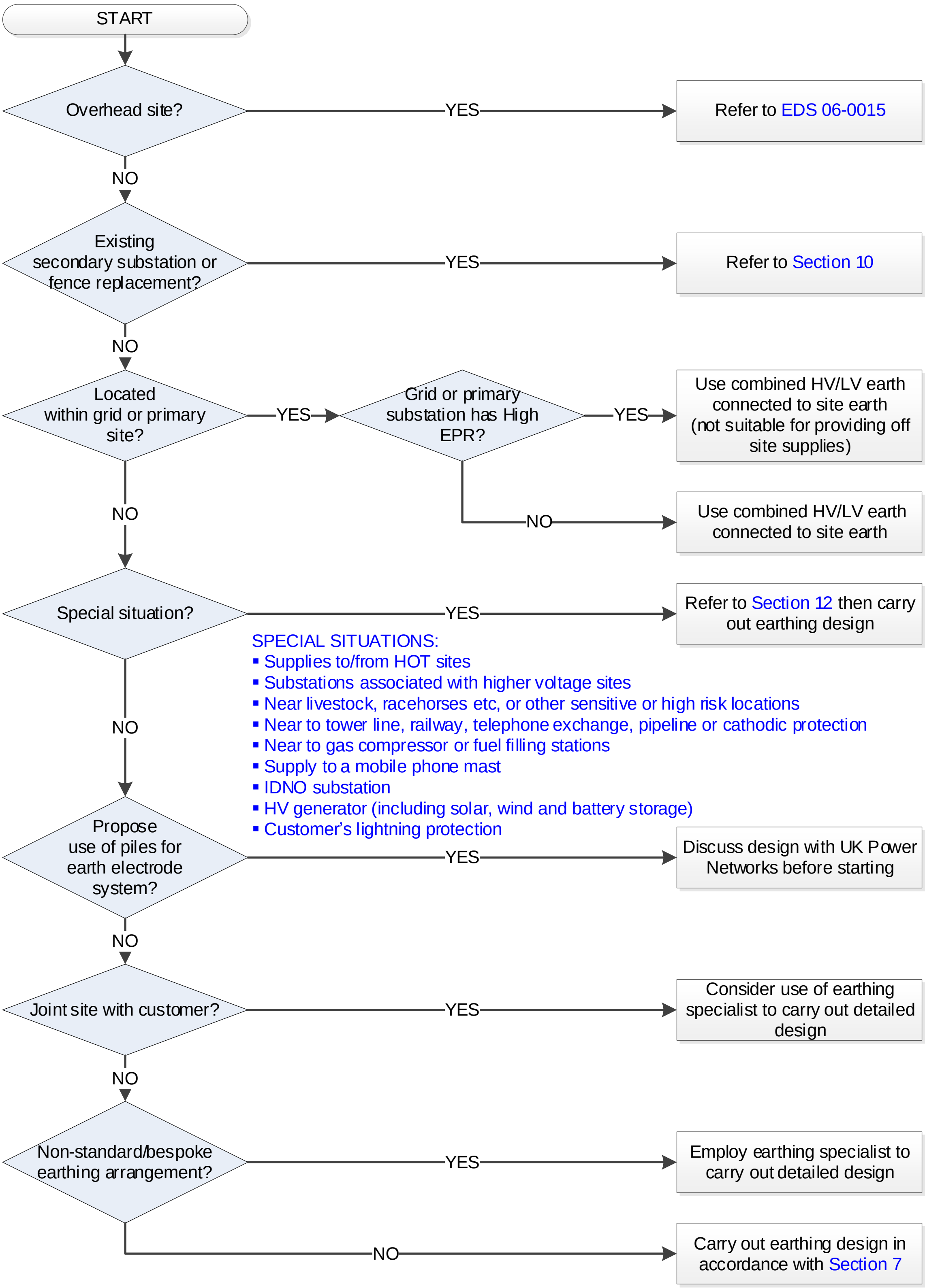


Figure 6-1 – Preliminary Earthing Design Assessment Flowchart

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 which provide further detail on each of the steps required to complete the earthing design.

The SSEDT (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 or EDS 07-4055.

External connection providers shall provide the information detailed in Section 13 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 to produce a supporting report and drawing.

7.2 Data Requirements

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

- Source grid/primary substation earth fault level, earth resistance and earth potential rise.
- Earth fault level at the secondary substation.
- Details of the cable or overhead line network between the source and the secondary substation including lengths, types, cable screen cross-section, etc.
- Supply circuit distance between the source and secondary substations.
- Soil resistivity at the secondary substation location.
- Fault clearance time for an earth fault at the secondary 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.

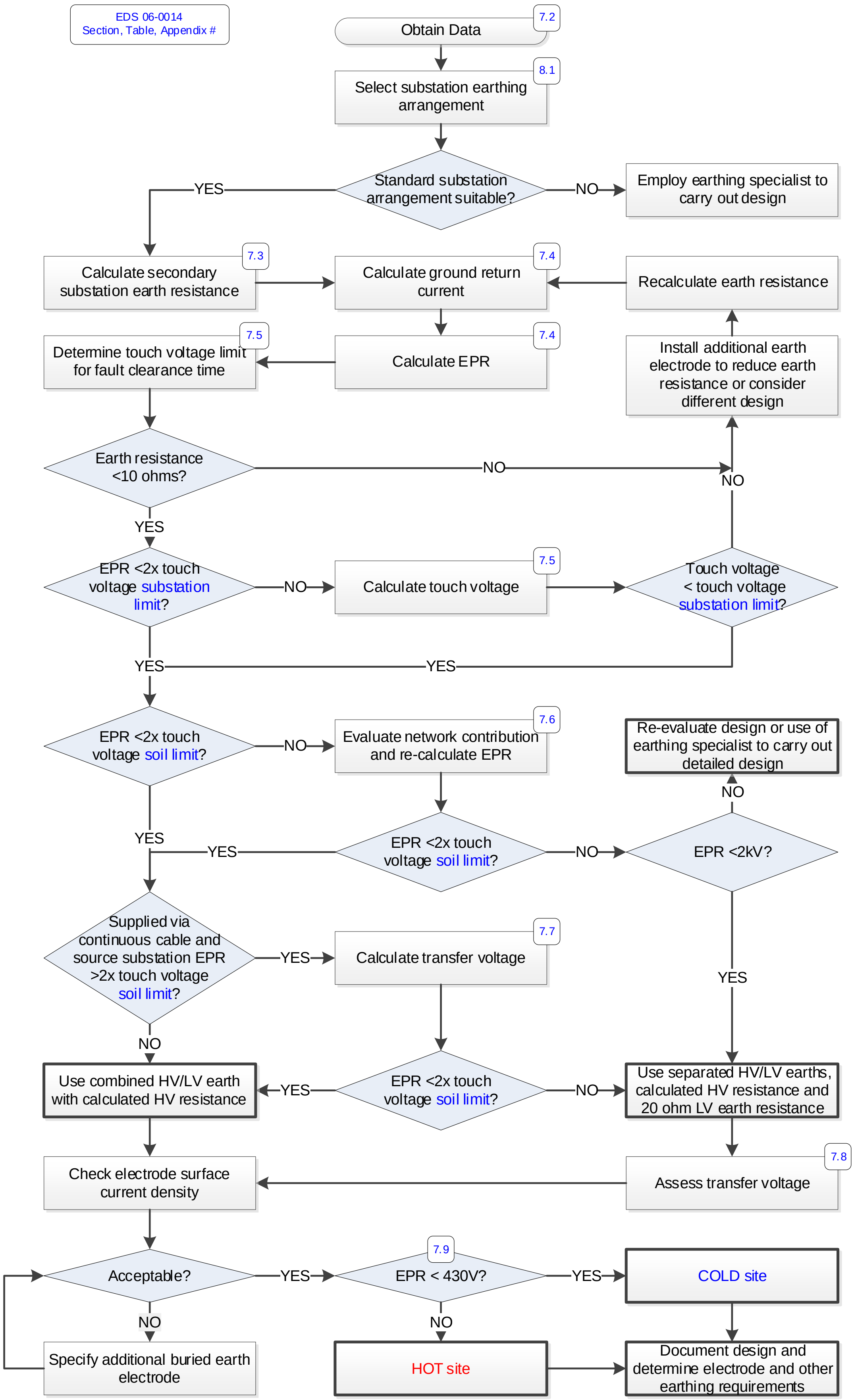


Figure 7-1 – Earthing Design Procedure Flowchart

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 longer earth rods and/or additional electrodes can be used to provide the desired value of earth resistance.

2. Estimate the substation HV electrode resistance (R_{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 SSEDT, GSA, NetMap (refer to EOS 06-0006 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 11.5 for information.

4. If the earth resistance is greater than 10Ω, longer earth rods or additional earth electrode shall be included to reduce the earth resistance.

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 conservative 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 assumed (unless additional calculations are provided by an earthing specialist).

   - 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 source and secondary 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 voltage shall be based on the EPR calculated using the standalone earth resistance from the substation earthing arrangement and any additional earth electrode only. The parallel earth resistance contribution from the network contribution **shall not** be used in the safety calculations.

Note: If the touch voltage is within the tolerable limits, the step voltage will also be within the corresponding step voltage limit.

Calculate the touch voltage and determine if it is acceptable as follows:

1. 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 added to the circuit-breaker operating time of either 100ms (oil) or 50ms (SF_6 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 a chipping/tarmac surface covering is installed.

2. Calculate the touch voltage using the following formula:

   $V_{Touch} = EPR \times \%_{Touch}$

   where $\%_{Touch}$ is the percentage of the EPR at which the maximum touch can occur.

> **Standard substation earthing arrangement touch voltage data** is available from EDS 06-0012 Appendix A. Alternatively, it can be calculated using computer simulation software.
>
> **Note:** If the design does not use a UK Power Networks standard earthing arrangement 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_{Touch}) is less than the touch acceptable limit ($V_{TouchLimit}$).

> **The latest touch and step voltage limits** are available from EDS 06-0012.

4. If the touch voltage exceeds the limit, further work is required to reduce the substation resistance and the EPR. The target value of R_{SecSub} can be calculated using the equation below. However, as the value of resistance changes the proportion of current returning through the earth also changes, therefore 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 chippings or tarmac surround) to achieve acceptable touch voltages.

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

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

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

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)

The HV and LV earths may be combined if EPR is less than the tolerable touch voltage limit on soil multiplied by an F-factor, e.g. 466V for a fault clearance time of 1s and F=2.

The F-factor relates to the percentage of EPR that will appear as a touch voltage on the LV network, and allows for the decay of the voltage transferred along a multiple earthed neutral conductor and the potential grading within an installation.

A value of F=2 should be used for multiple earthed systems (e.g. PME). If the LV neutral/earth conductor is only earthed at one point a value of F=1 should be used.

The touch voltage limit is based on the HV fault clearance time and the surface type, but it is also limited by the stress voltage limit of 1200V (refer to Section 3).

It may be necessary to further reduce the overall earth resistance to allow the HV and LV earths to be combined.

An underground cable network consisting of interconnected substations and metallic sheath cables – referred to as 'network contribution' – will provide a low earth resistance that will be in parallel with the resistance of the installed earthing system. Provided the substation earth resistance is below 10Ω and the touch voltage is within the applicable limits, the network contribution may be used in the EPR calculation.

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.

Further information on the application of **network contribution** and supporting **data** is available from EDS 06-0012 Appendix G.

Note: Network contribution is only applicable where there is a metallic earth connection (e.g. cable sheath/screen) between the substation and the part of the network providing the contribution and the contribution is typically within 2km. The contribution will be broken by overhead lines or diminish with excessive distance. Care is also required when substations are directly connected to the source grid/primary substation and there is no other network interconnection beyond the substation, network contribution is typically not applicable in this instance.

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 allow the HV and LV earths to be combined:

- The design shall be based on a practical installation with an earth resistance to ensure the EPR is below 2kV.
- The extent of the HV earth system should be limited.
- Separate HV and LV earths shall be installed.
- The transfer voltage to third parties and animals shall be assessed in accordance with Section 7.8.
- If the EPR exceeds 430V the site shall be classified as HOT in accordance with Section 7.9.

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 11.5. The resistance of the vertical piles is included in the calculations in a similar way to the network contribution described above.

Note 1: If the LV supply is only supplying the grid, primary or customer substation in which it is located, 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 HV/LV PILC cables.

7.7 Source Substation Transfer Voltage Calculation

The transfer voltage ($\mathrm{EPR_{Transfer}}$) from the source substation shall be calculated in the following circumstances:

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

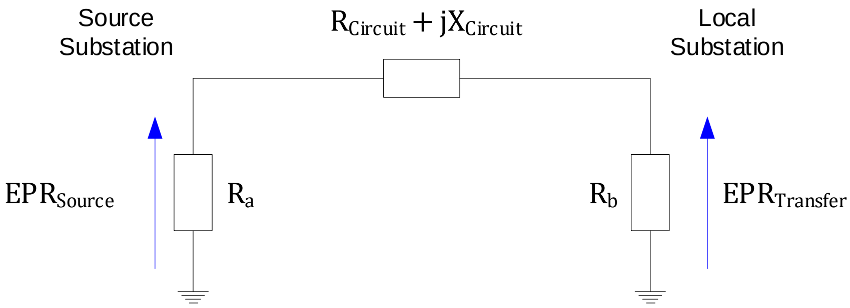


Figure 7-2 – Transfer Voltage

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 formula in EDS 06-0012 Appendix I.

3. If the transfer voltage exceeds the tolerable touch voltage limit separate HV and LV earths shall be installed.

The touch voltage limit is based on the fault clearance time associated with the voltage (i.e. 132kV, 33kV, 11kV) causing the transfer EPR and the surface type (e.g. 466V for a fault clearance time of 1s and F=2), but it is also limited by the stress voltage limit of 1200V (refer to Section 3).

4. The transfer voltage to third parties and animals shall be assessed in accordance with Section 7.8.

7.8 Transfer Voltage Assessment

If the EPR exceeds the tolerable touch voltage limit (from Section 7.6 and 7.7) a transfer voltage assessment shall be carried out to determine the impact on the following:

- Other LV earths e.g. PME, pole, street furniture, customer etc.
- Properties.
- Other infrastructure.
- Animals.

Generally, if an 8 metre separation can be maintained between all HV earth electrode (the electrode around the substation and any additional electrode) and there are no animals are involved no further mitigation is required.

If adequate separation is not possible or animals are present, a transfer voltage assessment shall be carried out to determine the relevant voltage contours and the impact – a sample plot is shown in Figure 11-7. This usually requires on-site measurements and a specialist earthing study. Refer to EDS 06-0002 for further information on the assessment and mitigation.

7.9 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 communications infrastructure, refer to EDS 06-0002 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. Communication Network Providers, e.g. Openreach, may also need to be notified in accordance with Section 12.10.

7.10 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 11.5).

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:

- GRP, brick-built and outdoor substations with a combined HV/LV Earth (Section 8.2).
- GRP, brick-built and outdoor substations with separated HV/LV Earths (Section 8.2).
- Compact or micro padmount substations without an enclosure (Section 8.3).
- Integral and basement substations (Section 8.4).
- Existing outdoor substations (Section 8.6).

The earthing arrangements have been incorporated into the standard secondary substation design drawings contained in EDS 07-3102 and the standard customer switchroom drawings contained in EDS 07-4055.

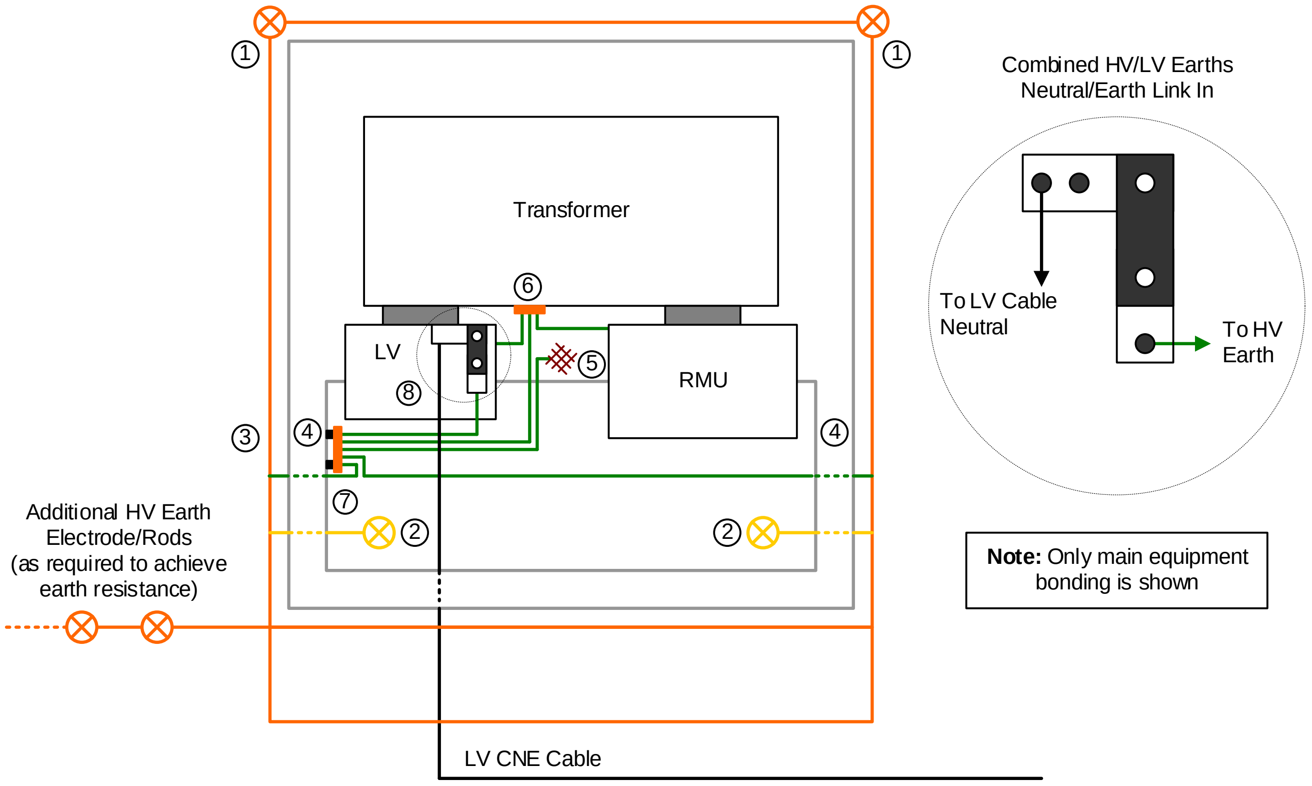
The **standard secondary substation and customer switchroom earthing arrangements** for different types of substation have been modelled in CDEGS to determine the **earth resistance values** in a range of different soils and the **safety voltage values**.

A full list of drawings and associated resistance/safety voltage data is available from EDS 06-0012 Appendix A. Refer to Appendix G for further information on the models.

Refer to Section 9 for further details on customer substations and switchrooms.

8.2 GRP and Brick-Built Substations

The general earthing arrangement for GRP, brick-built and outdoor[4] substations with a combined HV/LV earth is shown in Figure 8-1 and with separate HV/LV earths in Figure 8-2. Refer to EDS 07-3102 for specific designs.



Key	Earth rod	Bare electrode/conductor	Insulated electrode/conductor	
HV Earth Electrode/Conductor			**LV Earth Electrode/Conductor**	
Fault Level	**Copper Conductor**	**Copper Tape**	**Copper Conductor**	**Copper Tape**
Up to 8kA	70mm^2	25mm x 3mm	n/a	n/a
Up to 12kA	120mm^2 (or 2 x 70mm^2)	25mm x 4mm		
Up to 15kA	150mm^2 (or 2 x 70mm^2)	25mm x 6mm		

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 bar

5 - Minimum two connections to reinforcement rebar/mesh

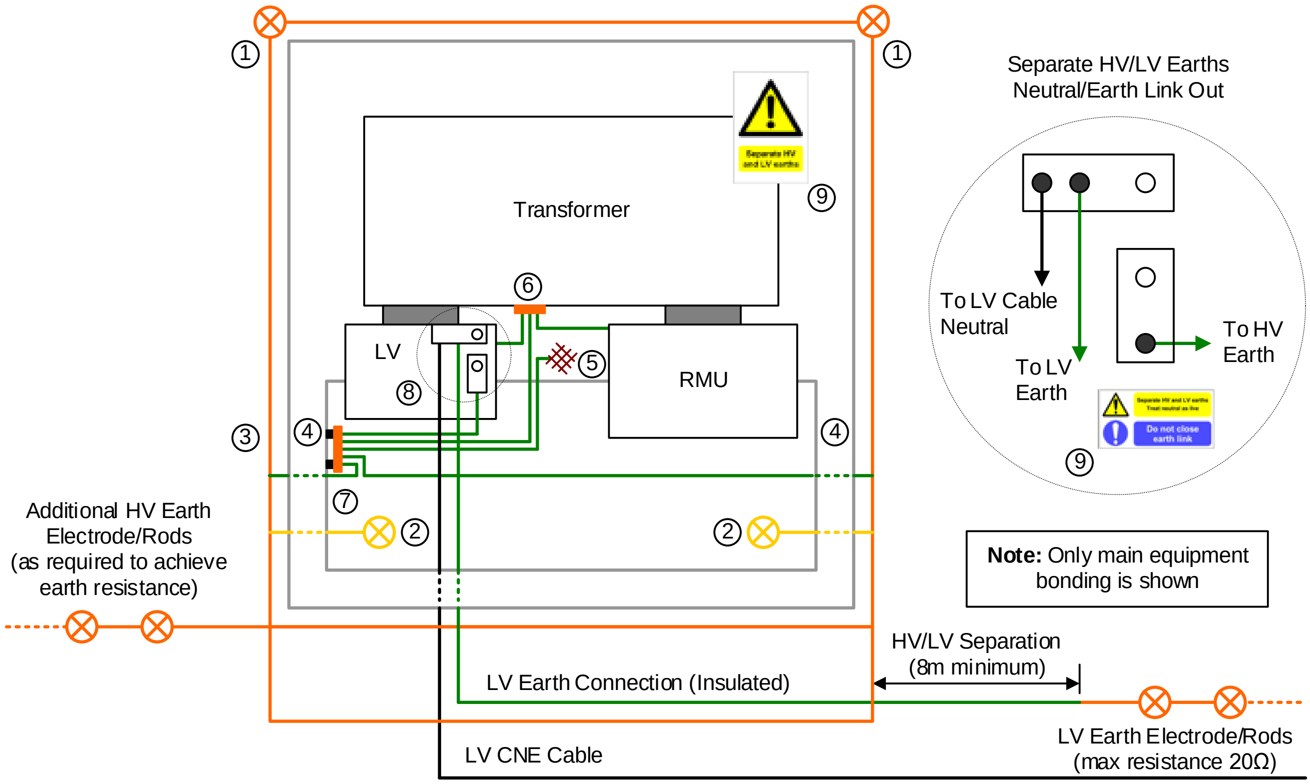
6 - Equipment bonding

7 - Earth bar (earth ring connections adjacent to each other allow clamp meter measurements)

8 - Neutral/earth link in place

Figure 8-1 – GRP or Brick-built Substation Earthing Arrangement for a Combined HV/LV Earth

[4] Outdoor secondary substations are not generally permitted for new build, however they may be used in specific situations, e.g. Areas of Outstanding Natural Beauty, where GRP and brick-built designs are not suitable.



Key	Earth rod	Bare electrode/conductor	Insulated electrode/conductor	
HV Earth Electrode/Conductor			**LV Earth Electrode/Conductor**	
Fault Level	**Copper Conductor**	**Copper Tape**	**Copper Conductor**	**Copper Tape**
Up to 8kA	70mm²	25mm x 3mm	70mm²	25mm x 3mm
Up to 12kA	120mm² (or 2 x 70mm²)	25mm x 4mm		
Up to 15kA	150mm² (or 2 x 70mm²)	25mm x 6mm		

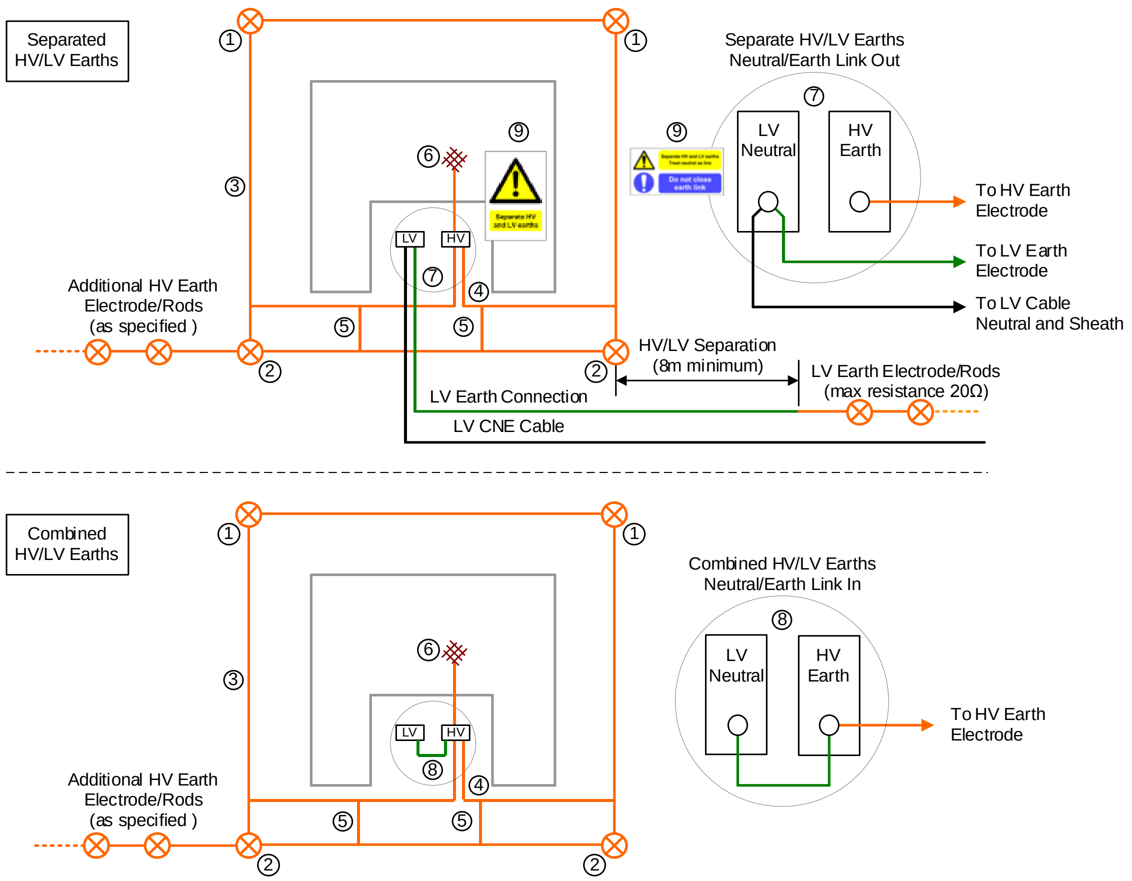
1 - 2.4m earth rods at rear corners
2 - Alternative internal 2.4m earth rods in place of external ones for brick-built substations
3 - Perimeter earth electrode around the outer edge of foundation buried at a depth of 500-600mm
4 - Earth electrode connecting each side of outer loop to main earth terminal
5 - Minimum two connections to reinforcement rebar/mesh
6 - Equipment bonding
7 - Earth bar (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 Separated HV/LV Earth

8.3 Padmount (including Micro and Compact) Substations

The earthing arrangement for a compact/micro substation without an enclosure is shown below. These are often supplied via the overhead network and therefore the HV and LV earths are typically separated. However, if specified in the design, 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 a padmount substation is installed in a GRP enclosure the standard arrangements shown in Section 8.2 shall be used.



Key	Earth rod	Bare electrode/conductor	Insulated electrode/conductor	
HV Earth Electrode/Conductor			**LV Earth Electrode/Conductor**	
Fault Level	**Copper Conductor**	**Copper Tape**	**Copper Conductor**	**Copper Tape**
Up to 8kA	$70mm^2$	25mm x 3mm	$70mm^2$	25mm x 3mm
Up to 12kA	$120mm^2$ (or 2 x $70mm^2$)	25mm x 4mm		
Up to 15kA	$150mm^2$ (or 2 x $70mm^2$)	25mm x 6mm		

1 - 2.4m earth rods at rear corners 500mm behind plinth

2 - 2.4m earth rods at front corners 500mm in front of the plinth

3 - Perimeter earth electrode around the substation, extending 500mm on all sides, buried at a depth of 500mm and connected to the earth rods

4 - Earth electrode connecting each side of outer loop to the main earth terminal

5 - Earth electrode in two places between the earthing ring and the earth terminal, passing directly underneath the positions where an operator is required to stand to open the front cover and carry out operations

6 - Connection to reinforcement rebar/mesh

7 - Neutral/Earth link removed 8 - Neutral/Earth link in place 9 - Warning labels

Figure 8-3 – Padmount Substation Earthing Arrangement Options

8.4 Integral and Basement Substations

The standard arrangements shown Section 8.2 should be used wherever possible. However, where the substation is situated within a building, 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, therefore it is important to achieve a low value of EPR to allow them to be combined. If it is not possible to obtain an EPR to allow the HV and LV earths to be combined 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 (refer to Section 8.5).

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 11.5).
- An embedded reinforcement mesh in a thin layer of concrete (Figure 8-4 (d)) to control the touch voltages around the equipment.
- A grading electrode in front of the doors as detailed in Section 11.6.2.1.

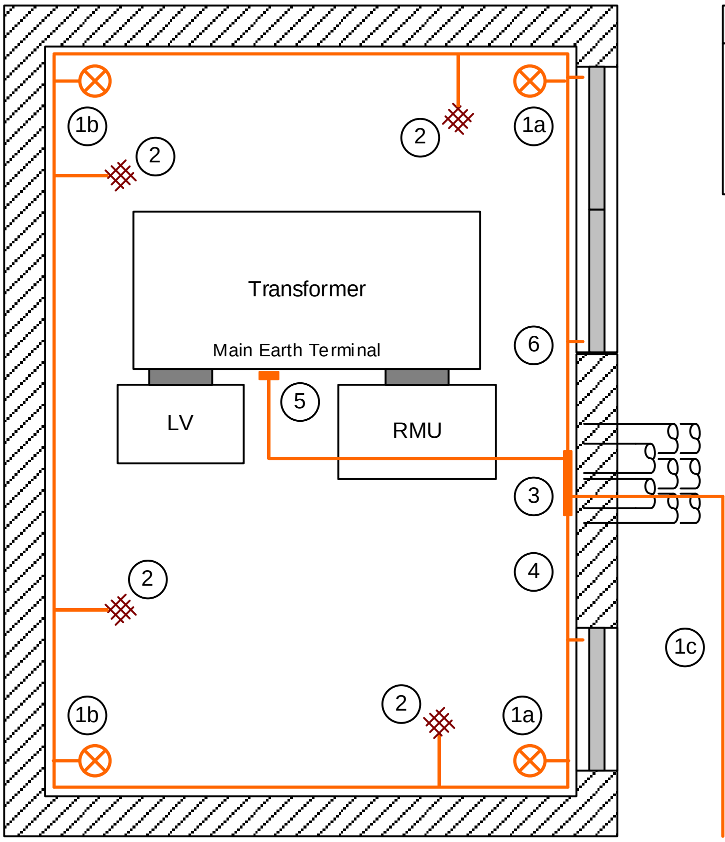
The following options, where practical, may be used to supplement the above:

- 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 11.5).

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

Refer to EDS 07-3102 and EDS 07-4055 for specific designs.

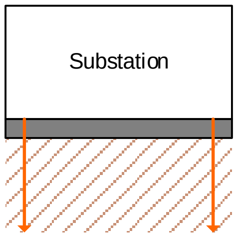
Note: Where the earth rods are installed in the basement, the connections between these and the substation shall be installed in accordance with Section 11.4.



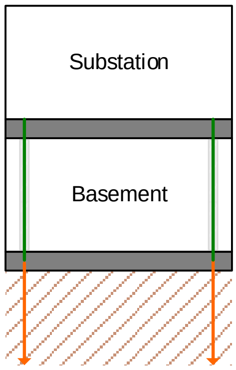
(a) Overall Earthing Arrangement

Key

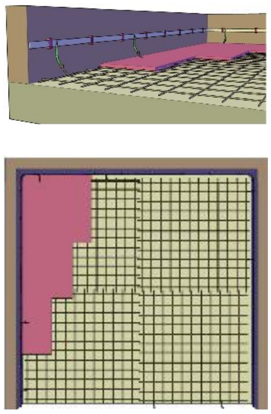
- Earth rod
- Bare electrode/conductor
- Insulated electrode/conductor



(b) Earth Rod Installation through Substation Floor into Soil



(c) Earth Rod Installation through Basement into Soil



(d) Embedded Mesh within Floor Screed

HV Earth Electrode/Conductor		
Fault Level	**Copper Conductor**	**Copper Tape**
Up to 8kA	70mm^2	25mm x 3mm
Up to 12kA	120mm^2 (or 2 x 70mm^2)	25mm x 4mm
Up to 15kA	150mm^2 (or 2 x 70mm^2)	25mm x 6mm

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

Figure 8-4 – Standard Design Approach for Integral and Basement Substation

8.5 Bespoke Substations

The standard arrangements described in the previous sections should be used wherever possible, however there are circumstances where it is not possible to install parts of the design and a bespoke earthing design is required.

All bespoke earthing designs, including those for raft type substations, should be carried out by an approved earthing specialist. The design shall be supported by a comprehensive earthing study including modelling to demonstrate compliance with the earth resistance and safety voltage requirements.

A typical bespoke GRP raft substation design is included in Appendix G.

8.6 Outdoor Substations

Outdoor (open compound) secondary substations are generally 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 Customer HV Supplies and Substations

9.1 Overview

The customer installation will generally be designed and built by a developer with reference to appropriate standards. It is not UK Power Networks role to carry out design work for a customer. However, UK Power Networks does have a duty of care to ensure that the earthing system of any customer substation connected to the distribution network is adequate in terms of safety and conforms to current UK earthing standards.

The earthing system for a customer installation shall as a minimum be designed in accordance with BS EN 50522, BS 7430, ENA TS 41-24 or the relevant the UK Power Networks standard.

The customer installation will be subjected to the same network operating conditions as the UK Power Networks substation therefore the information detailed Section 7.2 should be shared with the customer to allow them to carry out the 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. The connection will be refused, as outlined in Paragraph 26 of the Electricity Safety Quality and Continuity Regulations (ESQC Regulations) 2002, if UK Power Networks deem a substation to be unsafe.

9.2 Design

The UK Power Networks and customer earthing systems shall, wherever possible be designed as separate systems that can operate safely in the absence of the other. In this way, safety is ensured should they become disconnected from each other, or if the customer network is decommissioned. In most situations it is then acceptable to connect the customer and UK Power Networks earthing systems together.

In some circumstances, e.g. shared UK Power Networks and customer substations in shared buildings, an integrated earthing design (where safety of the UK Power Networks and/or customer earthing system relies on the interconnection with the other) may be required to achieve an optimal design.

Where an integrated earthing system is specified, the customer earthing system shall be constructed to UK Power Networks' standards (in terms of electrode/conductor sizing, method of installation and touch/step considerations). However, care is needed should the customer system become decommissioned or compromised; clear labelling and test facilities shall be provided to enable UK Power Networks to assess whether any customer contribution has been lost.

All integrated earthing designs shall be approved by UK Power Networks Asset Management.

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

The earthing arrangements for HV substations and switchrooms have been incorporated into the standard secondary substation design drawings contained in EDS 07-3102 and the standard customer switchroom drawings contained in EDS 07-4055.

The **standard secondary substation and customer switchroom earthing arrangements** for different types of substation have been modelled in CDEGS to determine the **earth resistance values** in a range of different soils and **safety voltage values**.

A full list of drawings and associated resistance/safety voltage data is available from EDS 06-0012 Appendix A. Refer to Appendix G for further information on the models.

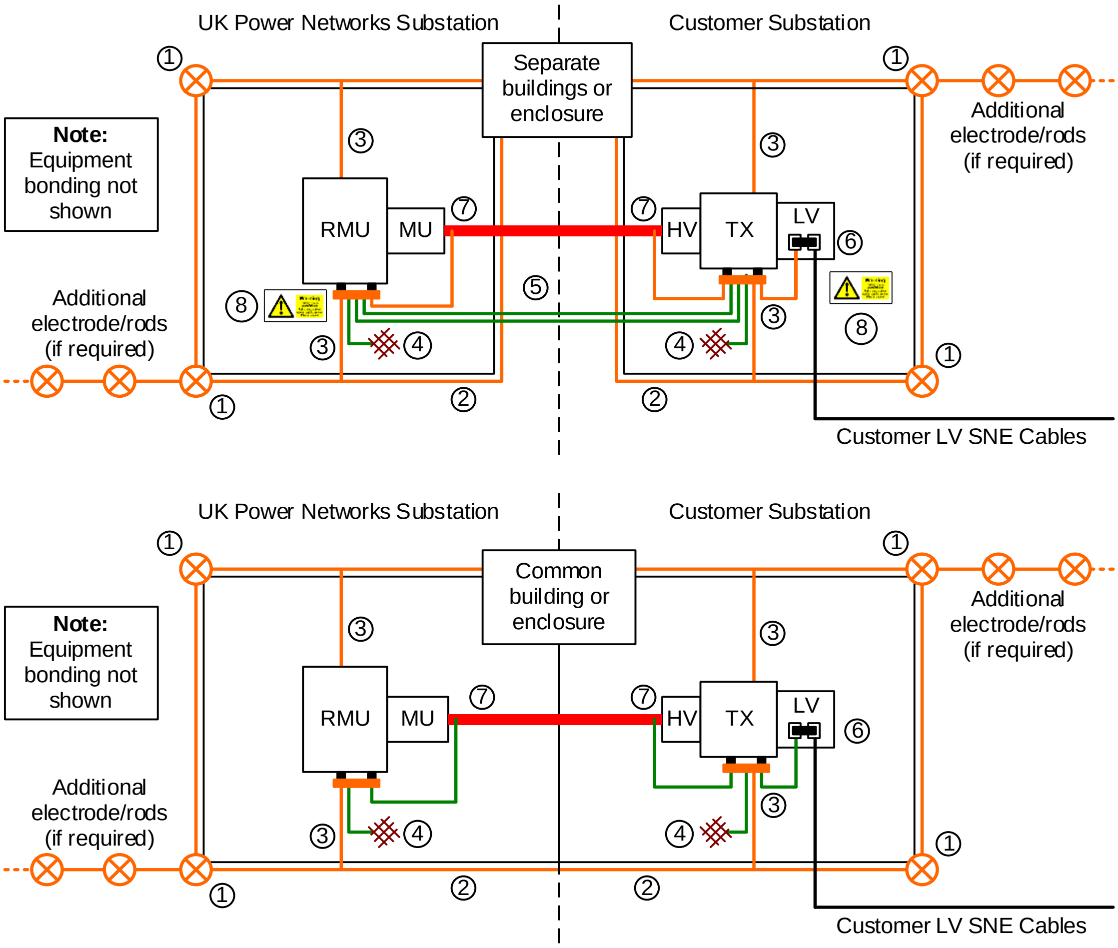
9.3 Other Requirements

The HV cable screen should be bonded to both earthing systems to provide a return path for any earth 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. The connection points shall be clearly labelled at both locations warning of the earth system inter-connection and bolted to facilitate disconnection under controlled conditions should this be necessary.

Once independent safety is achieved the combined resistance of both the UK Power Networks and the customer earthing systems can be used to calculate the overall EPR. The HV and LV earths can be combined if EPR does not exceed the tolerable touch voltage limit in accordance with Section 7.6 and 7.7.

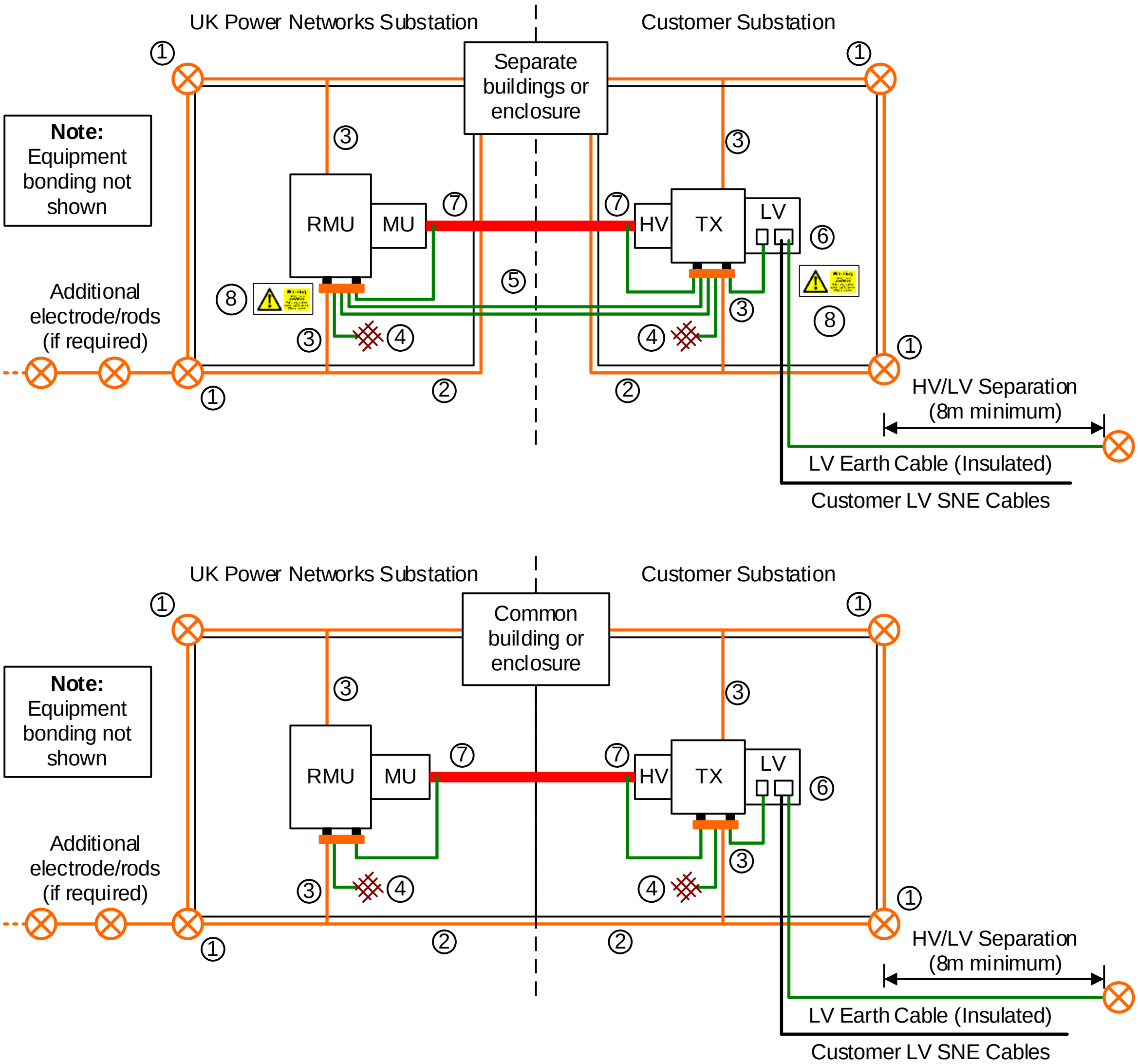
Examples for substations with combined and separated HV/LV earthing are shown in Figure 9-1 and Figure 9-2.



Key	Earth rod — Bare electrode/conductor — Insulated electrode/conductor

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 9-1 – Typical HV Supply and Customer Substation Arrangement for a Combined HV/LV Earth



Key — Earth rod — Bare electrode/conductor — Insulated electrode/conductor

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 removed
7 - HV cable screen bonded to earth at both ends
8 - Warning labels

Figure 9-2 – Typical HV Supply and Customer Substation Arrangement for a Separated HV/LV Earth

10 Existing Substation Earthing Assessment Procedure

The earthing at all existing substations shall be reviewed during supply upgrades, asset replacement or other works 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 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 flowchart in Figure 10-1 should be used to determine a suitable and compliant solution. Typically, 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 0.6m 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.
- 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, gate or door.

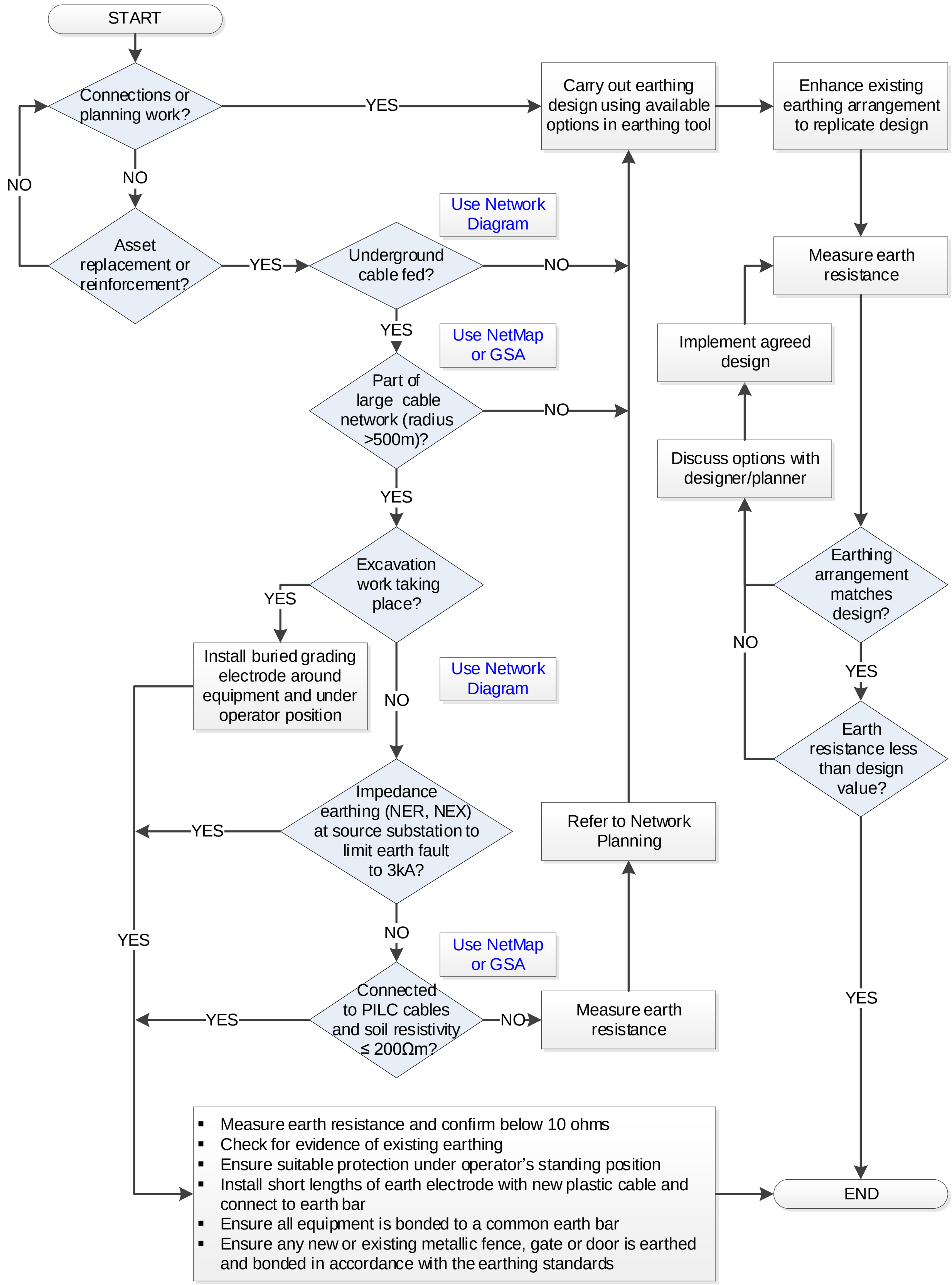


Figure 10-1 – Existing Substation Earthing Assessment Flowchart

11 Installation Requirements

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

- The requirements in Section 11.1 to 11.7 apply to all installations.
- If combined HV and LV earths are specified, the requirements of Section 11.8 also apply.
- If separated HV and LV earths are specified, the requirements of Section 11.9 also apply.

11.1 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 should be used for all above ground earthing wherever appropriate and practicable.

11.2 Electrode System

The earth electrode system shall provide the basic functional earthing for the site such 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 11-1. Dedicated earthing piles may also be used (refer to Section 11.5).
- 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 should 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 insulated connections from the perimeter earth ring (or each embedded mesh) onto a dedicated substation earth bar.
- An earth electrode passing underneath any HV 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.
- A minimum of two 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 where HV and LV earths are separated.
- Additional electrode and rods, as necessary, to achieve the required earth resistance.

Table 11-1 – Earth Electrode

Function	Source Fault Level[5]	Secondary Fault Level	Bare Copper Stranded Conductor*	Bare Copper Tape*
Earth Electrode	Up to 8kA	-	70mm^2	25mm x 3mm
	Up to 12kA	-	120mm^2 or 2 x 70mm^2	25mm x 4mm
	Above 12kA	Up to 8kA	120mm^2 or 2 x 70mm^2	25mm x 4mm
		Above 8kA	150mm^2 or 2 x 70mm^2	25mm x 6mm
Earth Rod Electrode	Any		16mm or 19mm Copper Clad Rods	
* Other equivalent conductor and tape sizes my used.				

[5] The earth fault level at the grid or primary substation supplying the secondary substation.

11.3 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 (integral/basement designs) which in turn shall be connected to the main transformer/switchgear earth terminal to allow:

- The earthing to be easily identified.
- Operational personnel to determine if the earthing is intact when entering the substation.
- The earth resistance to be measured using a clamp meter. The earth rod connections shall be next to each other to facilitate the measurement.

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.

11.4 Basement Earth Electrodes

All basement earth rods or piles used for earthing shall meet the following criteria:

- The arrangement shall include a minimum of two earth rods or piles.
- Each earth rod or pile shall have a dedicated independent connection to the substation earth bar, as follows:
  - The earth conductor or tape shall be insulated.
  - The earth conductor or tape between the substation and the rod or pile shall be installed in either steel conduit, pipe or trunking to provide mechanical protection.
- The earth rods should be located in a communal area accessible to UK Power Networks, for testing and maintenance purposes, and not in a third-party demise.

11.5 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 7.10) have 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 11-1.

The piles shall satisfy the requirements detailed in Section 11.4 and be connected as detailed in ECS 06-0022 which includes sample drawings.

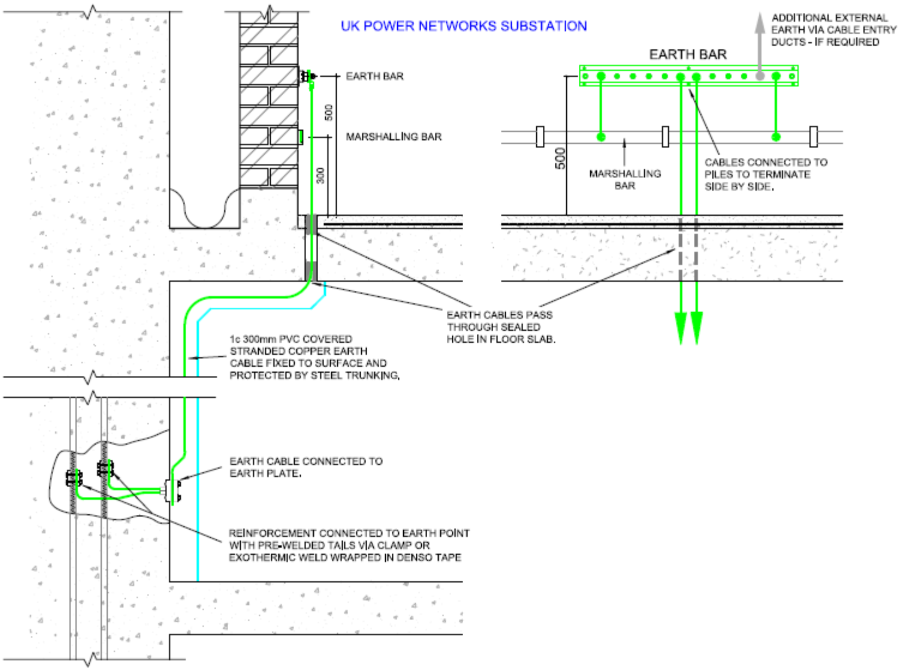


Figure 11-1 – Typical Pile Earthing

11.6 Bonding

11.6.1 Equipment Bonding

All current carrying items of equipment including the switchgear, LV pillar/cabinet/board and ACB shall be bonded to the substation earthing system using an independent connection. The minimum size of the bonding conductors is detailed in Table 11-2.

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[6].

Table 11-2 – Bonding Conductors

Function	Source Fault Level	Secondary Fault Level	Covered Stranded Cable*	Covered Tape*
Below or Above Ground Bonding	Up to 8kA	-	70mm^2 Copper	25mm x 3mm Copper
	Up to 12kA	-	120mm^2 or 2 x 70mm^2 Copper	25mm x 4mm Copper
	Above 12kA	Up to 8kA	120mm^2 or 2 x 70mm^2 Copper	25mm x 4mm Copper
		Above 8kA	150mm^2 or 2 x 70mm^2 Copper	25mm x 6mm Copper
Above Ground Bonding Only	Up to 8kA	-	120mm^2 Aluminium	25mm x 6mm Aluminium
	Up to 15kA	-	240mm^2 Aluminium	40mm x 6mm Aluminium
* Other equivalent conductor and tape sizes my used.				

[6] Minimum conductor sizes based on BS EN 50522.

11.6.2 Metallic Doors, Fences and Gates

Metallic doors, fences and gates require special attention as they can be touched by both staff and public. Both the touch voltage risk for persons making contact inside or outside of the substation and the hand-to-hand voltages between items of earthed substation equipment need to be managed.

Generally, infrastructure located outside the substation should not be bonded to the substation earthing system. If the infrastructure is within 2m of metalwork connected to the substation earthing system, separation, barriers or insulation should be considered before bonding to the substation earthing system.

The flowchart in Figure 11-2 outlines various options for doors, fences, and gates at substations with combined or separated HV/LV earths.

Third-party metallic fences shall be assessed separately in accordance with Section 11.6.2.3.

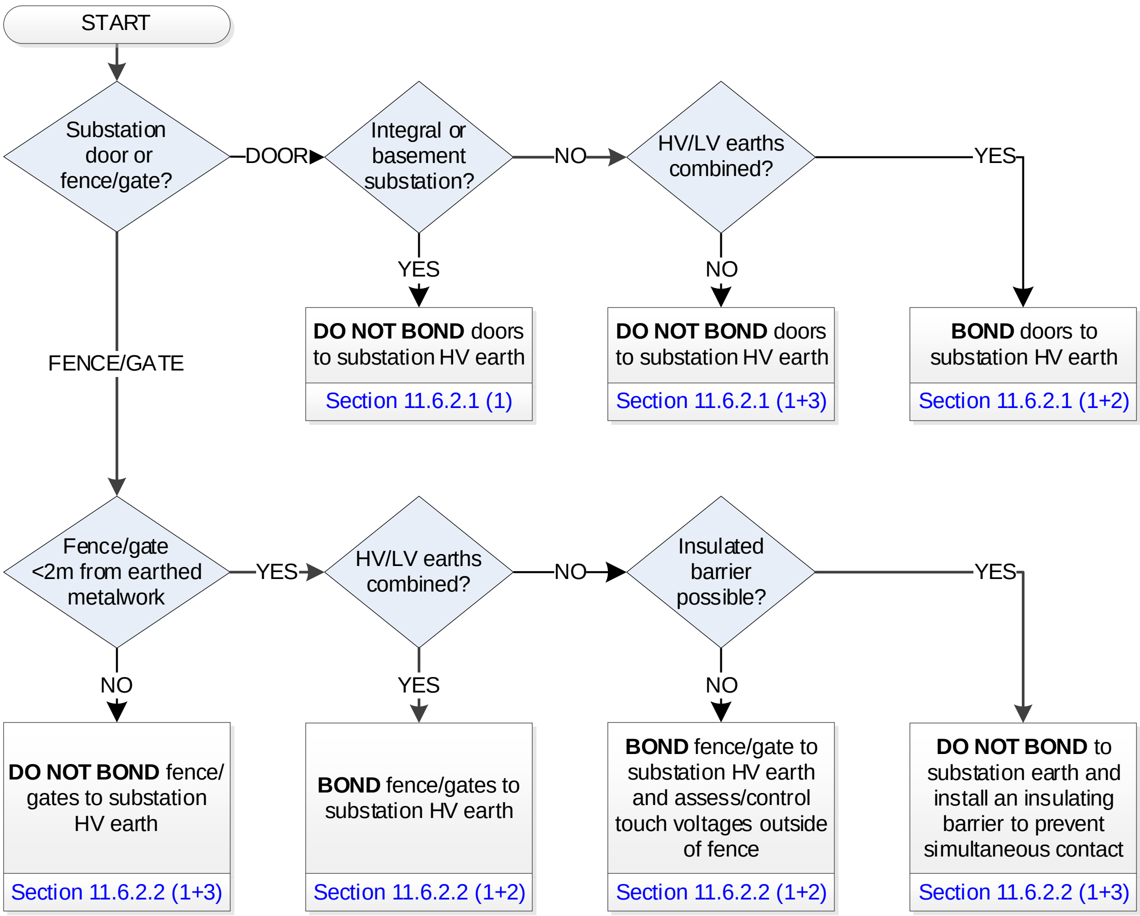


Figure 11-2 – Substation Metallic Doors, Fences and Gates Earthing Assessment Flowchart

11.6.2.1 Metallic Doors

1. For all substations:

   - Each door shall be connected to the framework using flexible 35mm^2 aluminium or 16mm^2 copper covered stranded cable or tinned copper braid.
   - Additional door cladding or anti-vermin guards shall be bonded to the door using flexible 35mm^2 aluminium or 16mm^2 copper covered stranded cable or tinned copper braid, unless welded in place.

2. For free-standing substations (with a buried perimeter electrode):

   - If the HV and LV earths are combined, the door frame and doors **shall** be connected to the HV earth.
   - If the HV and LV earths are separated the door frame and doors **shall not** be connected to the HV earth.

3. For integral and basement substations the door frame and doors **shall not** be connected to the HV earth.

11.6.2.2 Metallic Fences and Gates

1. For all installations:

   - Each metallic gate shall be bonded to the gatepost using flexible 35mm^2 covered stranded aluminium cable or 16mm^2 covered stranded copper cable or tinned copper braid.
   - Each pair of gateposts shall be bonded together using flexible 35mm^2 covered stranded aluminium or 16mm^2 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.
   - Apply the relevant requirements from (2) or (3) below.

2. If a metallic fence is **within 2m** of accessible earthed equipment the following additional requirements apply:

   - The fence shall be connected to the HV earth.
   - At substations with separated HV and LV earths, a grading electrode of 70mm^2 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.

3. If a metallic fence is **greater than 2m** from accessible earthed equipment the following additional requirements apply:

   - The fence **shall not** be connected to the HV earth.
   - An earth rod shall be installed at each fence corner/gate post and connected to the fence to eliminate stray voltages; where the fence panels are supported by metallic posts that are at least 1m deep in the ground, the posts can be considered as earth electrodes and additional earth rods are not required.

Note: Equipment inside a GRP enclosure is not considered to be accessible and therefore the **greater than 2m** requirements apply.

11.6.2.3 Third-party Metallic Fences

The guidance in this section is relevant to third-party fences associated with:

- Secondary substations contained within a metallic fenced compound (where the fence is connected to the substation HV earth).
- Padmount substations.
- Secondary substations in a non-metallic enclosure (e.g. GRP or brick) where the HV electrode is installed around the enclosure.
- Secondary substations with extended electrode to reduce the HV earth resistance.

Third-party metallic fences that are connected to, or within 2m of, a substation metallic fence or enclosure may transfer EPR to uncontrolled areas where the public may be exposed to a touch voltage hazard. A hand-to-hand touch voltage hazard may also exist if simultaneous contact is possible between the third-party metallic fence and an earthed substation enclosure. This guidance is an extension of the accepted fence earthing practice described in ENA TS 41-24.

The provisions should be included during the design of new substations and applied retrospectively to asset replacement projects.

The flowchart in Figure 11-3 should be used to assess the situation and determine the most suitable method of mitigation. The mitigation methods (A, B and C) are described in sub-section a), b) and c) respectively.

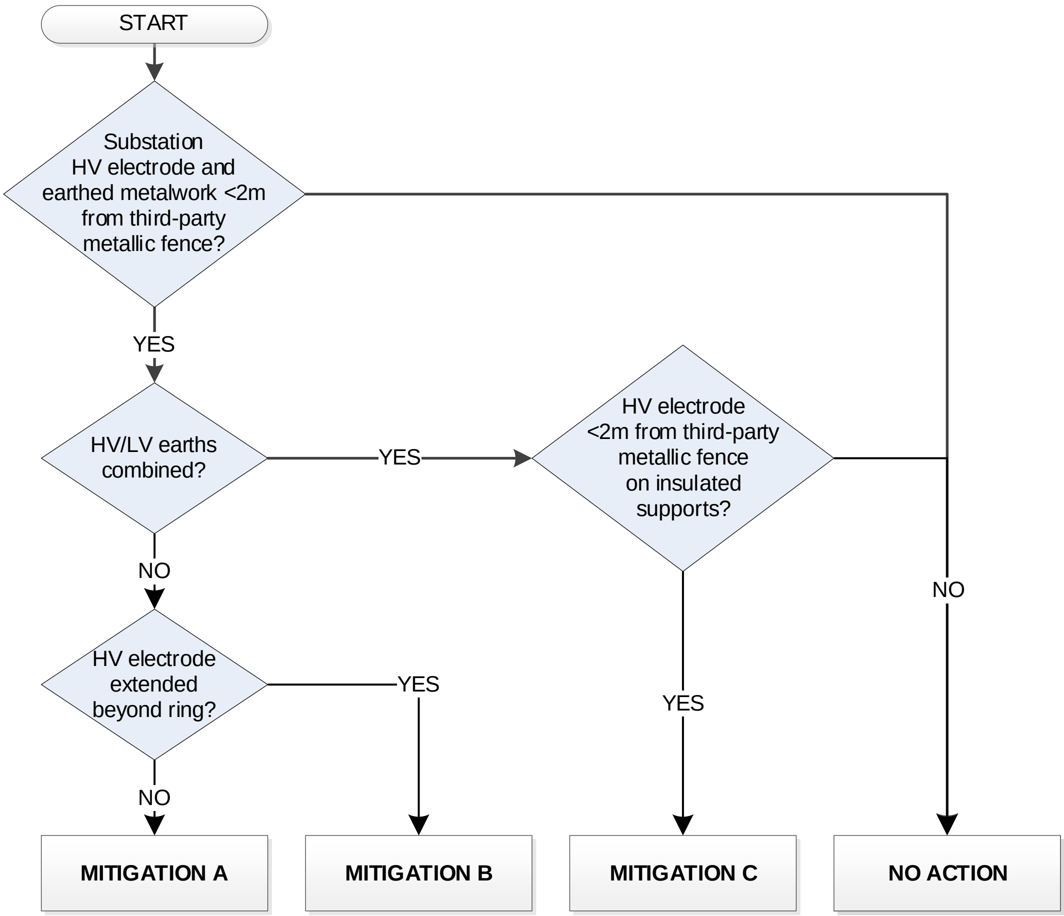


Figure 11-3 – Third-party Metallic Fence Earthing Assessment Flowchart

a) Mitigation A – Third-party Metallic Fence Abutting or Within 2m of Substation Earthed Metalwork or HV Electrode

This section applies where:

- The HV and LV earth separated.
- The HV electrode is confined to substation perimeter.

Where practicable, the design should be revised such that a third-party metallic fence is not directly connected to the substation enclosure or fence and is segregated from the HV electrode by a minimum of 2m. Where this is not possible an insulating or standoff fence panel(s) shall be introduced into the fence line to maintain separation as shown in Figure 11-4 and detailed below.

- The third-party metallic fence abutting the substation shall be fitted with an insulated panel for the first 2m as shown in Figure 11-4.
- The third-party metallic fence within 2m of the substation shall be fitted with two insulated panels such that there is a minimum of 2m separation between the substation earthed metalwork / HV electrode and the continuation of the fence, as shown in Figure 11-4. Alternatively, the fence section that is within 2m of the substation shall be replaced with non-conductive fence.
- 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 that 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.

For further information on the use of insulated panels and stand-offs refer to ECS 06-0022.

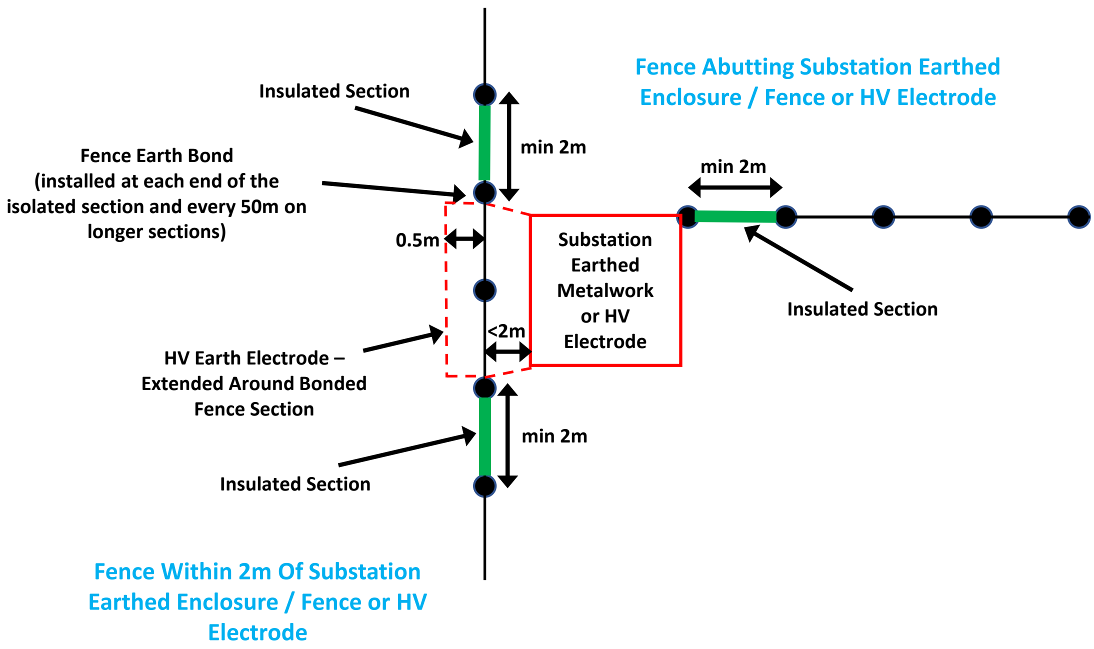


Figure 11-4 – Third-Party Metallic Fence Mitigation A

b) Mitigation B – Third-party Metallic Fence Within 2m of Substation Extended HV Electrode

This section applies where:

- The HV and LV earth separated.
- The HV electrode extends beyond the substation perimeter.

Where practicable, the design should be revised such that the HV electrode is more than 2m away from the third-party metallic fence., this section extends the principles of Mitigation A to a substation with an extended HV electrode, as shown in Figure 11-5 and detailed below.

Where this is not possible the mitigation detailed below and shown in Figure 11-5 (which extends the principles of Mitigation A) shall be applied:

- A third-party metallic fence within 2m of the HV electrode shall be fitted with two insulated panels such that there is a minimum of 2m separation between the substation earthed metalwork / HV electrode and the continuation of the fence, as shown in Figure 11-5.
- Alternatively, the fence section that is within 2m of the substation shall be replaced with a non-conductive fence.

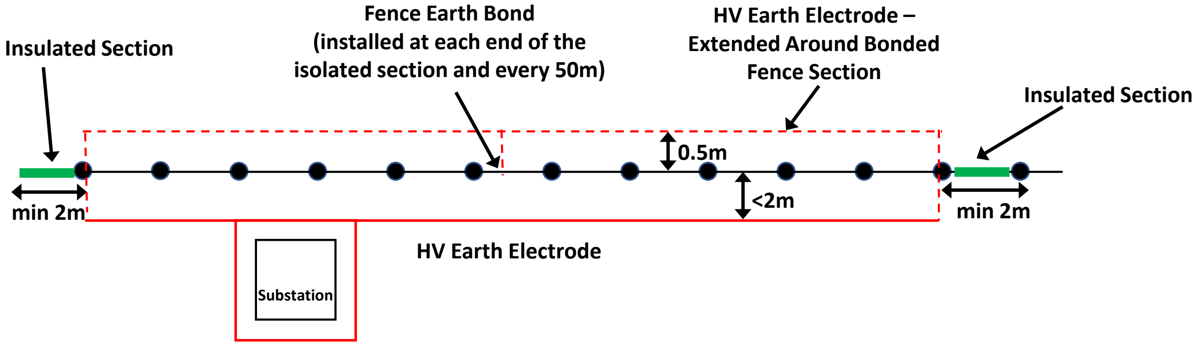


Figure 11-5 – Third-Party Metallic Fence Mitigation B

c) Mitigation C – Third-party Metallic Fence on Insulated Supports Within 2m of Substation HV Electrode

This section applies where:

- The HV and LV earths are combined.
- The third-party fence on insulated supports (e.g. barbed wire fences on wooden posts or mesh fences on concrete posts).

Where practicable, the design should be revised such that the HV electrode is more than 2m away from the third-party metallic fence. Where this is not possible, the mitigation detailed below and shown in Figure 11-6 shall be applied:

- An earth rod shall be connected to the fence at the extents of the HV electrode and one installed at the centre, as shown in Figure 11-6. For long sections an additional rod should be connected every 50m in between the others.
- Alternatively, the fence shall be replaced with a non-conductive fence along the entire length where the HV earth electrode is within 2m of the fence.

Note: As the HV and LV earths are combined, the additional fence rods replicate the multiple earthing associated with a PME LV earthing system, reducing the difference in potential between the fence and the local soil, to allow the F=2 assumption to be applied.

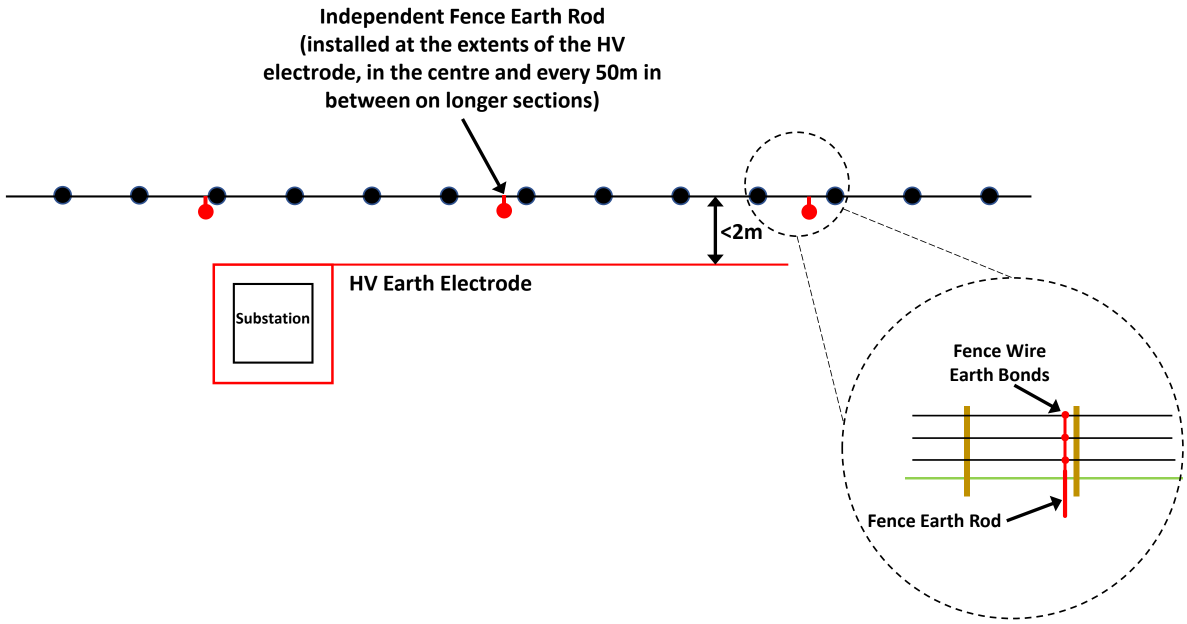


Figure 11-6 – Third-Party Metallic Fence Mitigation C

11.6.2.4 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. Palisade, 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.

11.6.3 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 a larger area where the 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. Therefore, in most cases bonding the cladding/panels to substation door frame and ensuring the door frame and doors are **not** bonded to the substation earthing system is the most practical solution and provides an acceptable risk.

However, where the HV and LV earths are separated and the building structure/cladding is likely to be connected to the LV earth, additional measures may be 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. Review the earthing design to allow combined HV and LV earths.

2. 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.

3. Bond the cladding/panels in the 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.

Note 1: The guidance on third-party fences detailed in Section 11.6.2.3 may assist with the application of options 2 and 3 above.

Note2: It is recommended that an earthing specialist is consulted on the most appropriate solution.

11.6.4 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[7], shall be taken to minimise risk to the public:

- Bond the ducts and ventilation shafts to the HV earth (unless the substation has separate HV and LV earths), 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.

11.6.5 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 has separate HV and LV earths refer to Section 11.9.

11.6.6 Ancillary Metalwork

At substations with combined HV and LV earths, all other exposed and normally un-energised metalwork inside the substation perimeter (e.g. supporting poles, 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[8].

At substations with separated HV and LV earths, 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 supported up by an appropriate risk assessment. Also refer to the guidance for ventilation shafts in Section 11.6.4.

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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[7] 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,

[8] Minimum conductor sizes based on BS EN 50522.

11.7 Cables

11.7.1 HV and LV Cables

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

All LV cables shall be bonded as follows:

- **CNE cables** - the neutral conductor shall be connected to the neutral bar in the LV pillar/cabinet/board in accordance with the LV Cable Jointing manual.
- **SNE cables** - the neutral conductor, earth conductor and any screen or armour shall be connected to the neutral bar in the LV pillar/cabinet/board in accordance with the LV Cable Jointing manual.

11.7.2 Customer Cables

The customer HV cable screens shall be connected to earth at both ends unless otherwise specified.

All LV and multicore cables that originate from a customer installation **shall not** be connected to the UK Power Networks substation earthing system (i.e. they shall only be earthed at the customer switchroom). All cable screens, armours etc. shall be insulated and protected in the UK Power Networks substation to prevent a shock hazard.

11.8 Combined HV/LV Earths

If the substation is designed with a combined HV/LV earth, a separate 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 such that the HV and LV earths are combined.

11.9 Separate HV/LV Earths – Additional Requirements

If the substation has separated HV and LV earths, the additional requirements detailed in this section shall be applied where necessary.

Extra care is required to ensure that:

- All metalwork connected to the substation HV earth is more than 2m from any other metalwork, pipework etc.
- HV and LV earths are separated by a minimum of 8m[9] and are not inadvertently combined.
- All spare LV tails and pot-ends are outside the relevant voltage contour.
- Any additional PME or TT earth electrodes are installed outside the relevant voltage contour.
- All properties with LV supplies are outside the relevant voltage contour.

Note: The relevant voltage contour shall be assumed to be 8m[9] around any HV earth electrode (including the electrode around the substation and any additional electrode installed in the cable trench) as shown Figure 11-7, unless the earthing system has been modelled[10] to determine a smaller zone or other mitigation is in place. Refer to Section 7.8 for further information.

[9] The 8m segregation distance is based on a maximum EPR of 2kV.

[10] Earthing system modelling is carried out using CDEGS (or other similar software) by an earthing specialist. Contact the document author if this service is required.

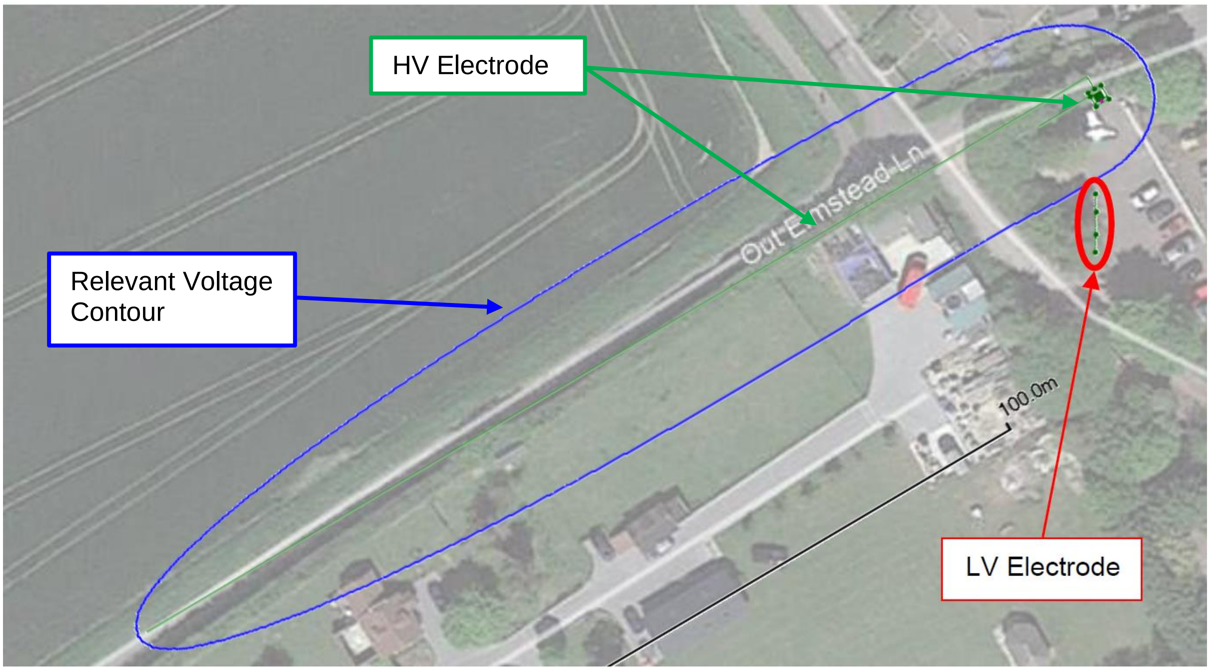


Figure 11-7 – Relevant Voltage Contour Example

11.9.1 LV Earth

A separated LV earth electrode shall be:

- Installed to provide a resistance of 20Ω or less.
- Separated from **all** HV electrode (including the electrode around the substation and any additional electrode installed in the cable trench) by **at least 8m**.
- Installed under an LV mains cable in the cable trench wherever practicable to enhance its security.
- Connected to the **neutral bar** in the LV pillar/cabinet using 70mm^2 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 it may not be possible to ensure separation of HV and LV earths, and further work may be required to reduce the EPR to allow them to be combined.

11.9.2 Neutral-Earth Link

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

11.9.3 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.

11.9.4 Lighting and Socket Supplies

Care is required when providing power and lighting supplies to substations with separate HV and LV earths to ensure that an operator cannot simultaneously touch metalwork connected to the different earthing systems.

Therefore, at substations with separate HV and LV earths:

- An isolation transformer[11] with a minimum 5kV insulation rating shall be used to supply the distribution board and used for lighting and RTU supplies only (all unused ways shall be blanked off).
- Light switches and conduits shall 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.

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.

11.9.5 Street Furniture

New substations with separate HV and LV earths shall not be installed within 8m of street lighting columns or other street furniture (e.g. electric vehicle charging points). An 8m separation is also required between the street furniture 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 (TT earthing system) and shall **not** use the neutral/earth of a PME service.

11.10 LVAC Supplies

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

For supplies to grid, primary or National Grid substations also refer to Section 12.4.

[11] The isolation transformer prevents the neutral (which is effectively another earth as it earthed at the source transformer) from being distributed within the substation and reduces the likelihood of inadvertent contact and LVAC equipment failure (the voltage difference during a HV fault between the neutral and the HV earth could exceed the withstand rating of the LVAC distribution equipment).

12 Special Situations

12.1 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 12.2).
- Secondary substations within grid or primary substations (Section 12.3).
- Supplies to grid and primary substations, National Grid and High EPR sites (Section 12.4).
- Supplies from high EPR sites (Section 12.5).
- Substations near sensitive sites e.g. where footwear is not worn (Section 12.6).
- Substations near animals (Section 12.7).
- Substations near transmission tower lines (Section 12.8).
- Substations near railways (Section 12.9).
- Substations near to telephone exchanges (Section 12.10).
- Substations near pipelines (Section 12.11).
- Substations near cathodic protection systems (Section 12.12).
- Substations near gas compressor stations (Section 12.13).
- Substations near fuel filling stations (Section 12.14).
- IDNO substations (Section 12.15).
- HV generator (including solar, wind and battery storage) connections (Section 12.16).
- Lightning protection (Section 12.17).

12.2 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; 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 10.

Metallic fences, gates and doors require particular attention to ensure that they are correctly bonded in accordance with Section 11.6.2.

12.3 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 insulated duplicate connections from the earth bar.

Additional requirements may be necessary for High EPR sites – refer to Sections 12.4 and 12.5.

12.4 Supplies to Grid and Primary Substations, National Grid and High EPR Sites

For supplies to sites where the EPR exceeds the tolerable touch voltage limit (refer to Section 7.6 and 7.7) 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 grid and primary substations which do not exceed the criteria above are shown in Figure 12-1.

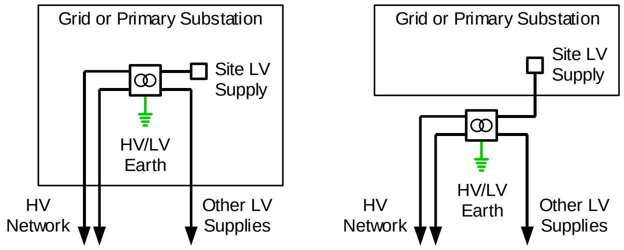


Figure 12-1 – Options for Supplies to Higher Voltage Substations

12.5 Supplies from Grid or Primary Substations with a High EPR

LV supplies shall **not** be taken from a grid or primary substation where the EPR exceeds the tolerable touch voltage limit (refer to Section 7.6 and 7.7) without the approval of Asset Management. However, Figure 12-2 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.
- A separate LV earth electrode shall be installed outside the relevant voltage contour.
- The LV cable and LV earth shall have an insulated sheath and be installed in an insulated duct (to withstand the maximum EPR of the site) inside the relevant voltage contour.
- 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 relevant voltage contour.
- Appropriate labelling shall be applied. Refer to EDS 08-2108 for examples.

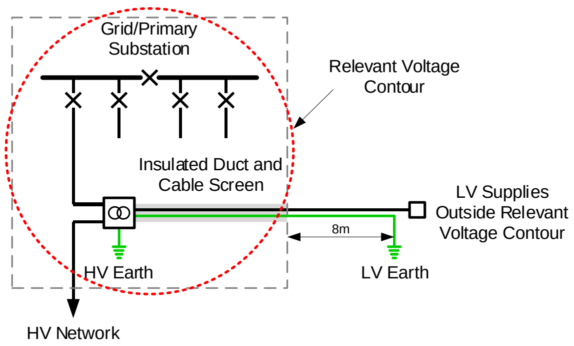


Figure 12-2 – LV Supply from a Grid or Primary Substation with a High EPR

12.6 Substations near Sensitive Sites

Sensitive sites include locations where footwear is not worn e.g. swimming pools, sports pavilions, camp sites etc.

Refer to EDS 06-0002 for further information on assessment and mitigation.

12.7 Substations near Animals

Animals are very susceptible to voltage gradients, therefore an additional safety assessment shall be carried for substations installed in areas where animals are or may be present, e.g. farms, stables, zoos, etc.

Refer to EDS 06-0002 for further information on assessment and mitigation.

12.8 Substations near Transmission Tower Lines

Secondary substations should, where possible, not be located within 50m of a 400kV, 275kV or 132kV tower. If the substation is situated within 50m of a tower, an earthing specialist should be employed to calculate the transfer voltage from the tower.

Refer to EDS 06-0002 for further information on the assessment and mitigation.

Refer to EDS 08-2109 for supplies to equipment mounted on transmission towers, e.g. mobile phone base stations, aircraft warning lights etc.

12.9 Substations near Railways

The conductive parts of substations (including the associated earthing system) and railway systems should be kept as far away as practicable to minimise interference and ideally by a minimum of 10m.

Generally, if a DC railway satisfies the requirements of BS EN 50122-2:2010, the system is assumed to be acceptable in terms of DC stray currents and separation or further mitigation is not required.

Note: BS EN 50122-2 suggests that for crossings of tracks with pipes or cables a minimum distance of 1m is adequate for stray current protection purposes. If operational experience suggests there is no adverse corrosion effects on local substations a similar approach may be applied where it is not possible to achieve 10m. However, if there is any uncertainty, additional sacrificial electrode should be considered to minimise the effects of DC erosion; one method is to double the rods and electrode that would normally be installed.

In addition to the above, the transfer voltage onto the railway infrastructure should also be considered. Refer to EDS 06-0002 for further information.

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

12.10 Substations near Telephone Exchanges

If the substation is classified as HOT and within 10m[12] of a telephone exchange the Communication Network Provider (e.g. Openreach) shall be informed and the appropriate information provided.

Refer to EDS 06-0002 for further guidance.

12.11 Substations 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 EN 50443.

Where the proposed substation location is within 50m of a buried pipeline a more detailed assessment may be required, refer to EDS 06-0002 for further information.

12.12 Substations 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.

The exact location of cathodic protection electrodes/rectifiers/anodes is usually unknown, therefore it is recommended that all substations are located 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.

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

12.13 Substations near Gas Compressor Stations

Substations, and the associated earthing system, located near to gas compressor stations require careful consideration to prevent corrosion of the station steelwork and pipework. Stainless steel earth rods, earth electrode and insulated conductor is typically used in place of bare copper. However, these changes impact the design criteria used for the standard substation arrangements (Section 8) and therefore advice from an earthing specialist should be sought to ensure the earthing system is satisfactory.

Useful references are National Grid standards T/SP/EL/13 and T/SP/COMP34.

[12] Source ENA EREC S36.

12.14 Substations near Fuel Filling Stations

Where a new secondary substation is required for a supply to a fuel filling station (e.g. for electric vehicle charging points) or a new supply is to be taken from an existing substation secondary at a fuel filling station, a more detailed assessment shall be carried out in accordance with EDS 06-0002 if any of following are exceeded:

- The substation is within 10 metres of a fuel filling station TT earthing system or any metalwork bonded to it (e.g. fuel vents, fuel pipes, fuel tanks, bonded rebar, extraneous metalwork).
- The proposed EPR is greater than 233V.
- The proposed HV fault clearance time exceeds 1 second.

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

Further guidance on the earthing of electric vehicle charging points is available from EDS 06-0017 Section 5.16 and BS 7671 Section 722.

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.

12.15 IDNO Substations

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

12.16 HV Generator Connections (including Solar, Wind and Battery Storage)

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 the relevant 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.

12.17 Cable Bridges

A cable bridge typically consists of a steel structure e.g. pipe or tray crossing a river. The main risk, although very unlikely, is a touch voltage on the bridge and any surrounding metalwork due to a voltage rise from a cable fault on or within the bridge.

As a minimum an earth rod with a maximum resistance of around 20Ω shall be installed at either end and connected to the cable bridge. The combined parallel resistance of both rods should be below 10Ω to ensure protection operation in the unlikely event of a cable fault. This would also help to control any induced voltage, although this is typically low due to the short length and trefoil arrangement.

If there is a perceived high risk of people touching the bridge, a more detailed study should be carried out to determine the value of resistance to achieve safe touch voltages. Alternatively, the bridge should be insulated, or barriers erected to prevent direct contact.

12.18 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 LPS does not exceed 10Ω and the substation has a combined HV/LV earth they should be connected together at the substation earth bar. The connection point shall be via a removable and clearly labelled link (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.

If the substation is located inside a larger building with lightning protection, the design shall consider the transfer voltage from the substation to other parts of the site via the lightning protection system.

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.

13 Third-party Design Assessment

13.1 Overview

Where the substation earthing is designed by a third-party (e.g. customer or ICP) they shall provide an earthing design report and earthing arrangement drawing as detailed in Sections 13.2 and 13.3 to enable UK Power Networks to assess the substation earthing design.

The submitted design should include sufficient information to enable UK Power Networks to understand and assess the design, without having to repeat the design process or calculations. If software plots are included, they should be clearly explained, and key values summarised in a table.

Earthing designs that do not include sufficient information or meet the minimum requirements specified in this standard may be unsafe and shall not be granted design approval. The connection will be refused, as outlined in Paragraph 26 of the Electricity Safety Quality and Continuity Regulations (ESQC Regulations) 2002, if UK Power Networks consider a substation to be unsafe.

13.2 Earthing Drawing

An earthing arrangement drawing shall be provided and include as a minimum:

- Substation layout with earthing arrangement.
- Main earth electrode(s) and depth, earth rods, rebar/reinforcement connections etc.
- Additional earth electrode required to obtain the earth resistance value.
- 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 metallic fencing, street furniture or other metallic structures.

13.3 Earthing Report

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

- Base data and source.
- Earth resistance.
- Ground return current.
- Earth potential rise (EPR) calculations.
- Touch and step voltage calculations (and supporting voltage contour plots if relevant).
- Transfer voltage calculations (if applicable).
- ITU limit calculations and plot of HOT zone (if applicable).
- Electrode surface area current density calculation.
- Details of any additional precautions that are required.

13.4 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.

13.5 Assessment Form

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

14 References

14.1 UK Power Networks Standards

EDS 06-0002	EPR and Transfer Voltage Management (including HOT Sites)
EOS 06-0006	Substation Earthing Data
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
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 07-4055	Customer Switchrooms for Indoor Switchgear
EDS 08-1101	IDNO Networks
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 Transmission Towers

14.2 National and Industry Standards

ENA TS 41-24[13]	Guidelines for the Design, Installation, Testing and Maintenance of Main Earthing Systems in Substations
ENA EREC G12[13]	Requirements for the Application of Protective Multiple Earthing to Low Voltage Networks
ENA EREC S34[13]	A Guide for Assessing the Rise of Earth Potential at Substation Sites
ENA EREC S36[13]	Procedure to Identify and Record HOT Substations
BS EN 50443	Effects of Electromagnetic Interference on Pipelines caused by High Voltage a.c. Electric Traction Systems and/or High Voltage a.c. Power Supply Systems
BS EN 50522	Earthing of Power Installations Exceeding 1kV AC
BS EN 62305	Protection against Lightning
BS EN 60079	Explosive Atmospheres
T/SP/EL/13	Specification for Earthing, National Grid
T/SP/COMP34	Specification for Electrical Equipment on Compressor Installations, National Grid

[13] ENA documents available from http://www.dcode.org.uk/annexes.html or www.energynetworks.org.

15 Dependent Documents

EOS 04-0035	Compact Substations
EDS 06-0001	Earthing Standard
EDS 06-0002	EPR and Transfer Voltage Management (including HOT Sites)
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
ECS 06-0022	Grid and Primary Substation Earthing Construction
ECS 06-0023	Secondary Distribution Network Earthing Construction
EDS 07-3101	Pre-design Requirements for Secondary Substations
EDS 07-3102	Secondary Substation Civil Design Standard
EDS 07-4055	Customer Switchrooms for Indoor Switchgear
EDS 08-1100	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 SSEDT. With the exception of soil resistivity this information is also available to external connection providers via the SSEDT or their UK Power Networks nominated contact.

Table A-1 lists the original data sources.

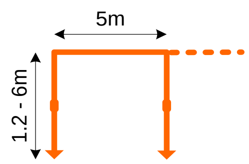
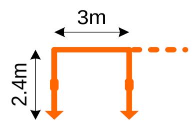
Table A-1 – Data Sources for Earthing Design Calculations

Data	UK Power Networks Source
Source substation earth fault current	DigSilent PowerFactory
Secondary substation earth fault current	GROND, DPlan
Source substation earth grid resistance	Asset Register (refer to EOS 06-0006) or use 0.1Ω if no value available
Source substation classification (HOT or COLD)	Asset Register (refer to EOS 06-0006)
Circuit details	NetMap, GROND, DPlan
Source protection details	Asset Register
Secondary substation standard earthing arrangements	EDS 06-0012 Appendix A
Secondary substation soil resistivity	NetMap (refer to EOS 06-0006)

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.

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

Typical Soil Type/Soil Resistivity		1Ω Earth Resistance		10Ω Earth Resistance		20Ω Earth Resistance	
		(a)	(b)	(a)	(b)	(a)	(b)
Loam	25Ωm	6 x 6m	11 x 2.4m	1 x 2.4m	1 x 2.4m	1 x 1.2m	1 x 2.4m
Chalk	50Ωm	13 x 6m	27 x 2.4m	1 x 6.0m	2 x 2.4m	1 x 2.4m	1 x 2.4m
Clay	100Ωm	34 x 4.8m	60 x 2.4m	3 x 4.8m	4 x 2.4m	2 x 4.8m	2 x 2.4m
Sand, Gravel, Clay mix	<150Ωm	Site specific design required		4 x 4.8m	7 x 2.4m	2 x 4.8m	3 x 2.4m
	<200Ωm	Site specific design required		5 x 4.8m	9 x 2.4m	3 x 4.8m	4 x 2.4m
	>200Ωm	Site specific design required					
Slate, Shale, Rock	500Ωm	Site specific design required					
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[14]. 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[14]. The top of each electrode shall be at a minimum depth of 0.6m below ground level					

[14] 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

No of Rods	Rod Length (m)	Resistance (Ω)[15]							
		25Ωm	50Ωm	100Ωm	150Ωm	200Ωm	300Ωm	400Ωm	500Ωm
1	1.2	17.9	35.8	71.6	107.4	143.2	214.7	286.3	357.9
2	2.4	10.1	20.2	40.4	60.6	80.8	121.2	161.5	201.9
3	3.6	7.2	14.4	28.7	43.1	57.4	86.1	114.9	143.6
4	4.8	5.6	11.2	22.5	33.7	45.0	67.5	90.0	112.5
5	6.0	4.6	9.3	18.6	27.9	37.2	55.8	74.3	92.9
6	7.2	4.0	7.9	15.9	23.8	31.8	47.7	63.6	79.5
7	8.4	3.5	7.0	13.9	20.9	27.8	41.7	55.6	69.6
8	9.6	3.1	6.2	12.4	18.6	24.8	37.2	49.6	62.0
9	10.8	2.8	5.6	11.2	16.8	22.4	33.6	44.8	56.0
10	12	2.6	5.1	10.2	15.3	20.4	30.6	40.8	51.1
11	13.2	2.3	4.7	9.4	14.1	18.8	28.2	37.6	47.0
12	14.4	2.2	4.4	8.7	13.1	17.4	26.1	34.8	43.6
13	15.6	1.9	3.8	7.7	11.5	15.4	23.1	30.8	38.5
14	16.8	1.8	3.6	7.2	10.9	14.5	21.7	28.9	36.2
15	18	1.8	3.6	7.2	10.7	14.3	21.5	28.7	35.8
16	19.2	1.7	3.4	6.8	10.2	13.5	20.3	27.1	33.9
17	20.4	1.6	3.2	6.4	9.6	12.8	19.3	25.7	32.1

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

Conductor/Mat Length		Resistance (Ω)[16]								
		25Ωm	50Ωm	75Ωm	100Ωm	150Ωm	200Ωm	300Ωm	400Ωm	500Ωm
Conductor	10m	6.1	12.2	18.3	24.4	36.6	48.8	73.1	97.5	121.9
	25m	2.7	5.5	8.2	10.9	16.4	21.8	32.8	43.7	54.6
	50m	1.5	3.0	4.4	5.9	8.9	11.8	17.7	23.6	29.5
	100m	0.8	1.6	2.4	3.2	4.8	6.3	9.5	12.7	15.9
	150m	0.5	1.1	1.6	2.2	3.3	4.4	6.6	8.8	11.0
	200m	0.4	0.8	1.3	1.7	2.5	3.4	5.1	6.8	8.5
	250m	0.3	0.7	1.0	1.4	2.1	2.8	4.2	5.5	6.9
	500m	0.2	0.4	0.6	0.7	1.1	1.5	2.2	2.9	3.7
1m x 1m Lattice Mat in Soil		13.2	26.3	-	52.6	79.0	105.3	157.9	210.6	263.2
1m x 1m Lattice Mat in Earthing Compound		3.7	7.3	-	14.7	22.0	29.3	44.0	58.6	73.3

[15] Rod resistance calculated using formulae R1 from ENA EREC S34.
[16] Conductor resistance calculated using strip earth electrode formulae from BS EN 50522 and earth mat resistance calculated using formulae R4 from ENA EREC S34 with 1m copper lattice.

Appendix C – Earthing Forms

Earthing data, design and construction forms (EDS 06-0014C) are available within the SSEDT.

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

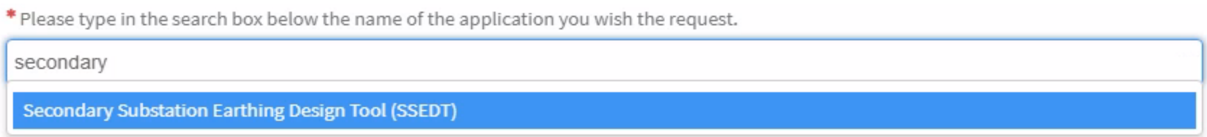
Appendix D – Earthing Design Assessment Form

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

Appendix E – Secondary Substation Earthing Design Tool (SSEDT)

The SSEDT is hosted in Microsoft Azure Virtual Desktop (AVD).

UK Power Networks staff can request the SSEDT via MyIT > Do you want something? > Software Installs and Application Access > In-house Application Request.Type ‘secondary’ into the search box, select ‘Secondary Substation Earthing Design Tool (SSEDT)’ (as shown below) and complete the request in the usual way.



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

A user guide and eLearning training is available via the **Help** menu in the SSEDT.

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 Earthing Arrangement Models

The earth resistance for different earth rods lengths, touch and step voltage percentages and voltage profiles for each secondary substation earthing arrangement are available as a separate document EDS 06-0014G (internal document only).