1. SCOPE

This technical specification describes SPEN's requirements for earthing and bonding systems at secondary substations. This includes all HV/LV substations, HV only substations, HV pole-mounted installations, HV customer substations and IDNO/DNO shared substations up to and including 11 kV.

This specification allows SPEN to demonstrate compliance with relevant national and international standards as well as statutory legislation and licence conditions. This document has been issued to align with latest releases of the ESQCR, BS EN 50522, ENA TS 41-24 and ENA EREC S34.

2. ISSUE RECORD

This is a Reference document. The current version is held on the EN Document Library.

It is your responsibility to ensure you work to the current version.

Issue Date	Issue No.	Author	Amendment Details
25th Feb 2020	1	Kevin Butter Stephen Batten Eric Paalman	This document replaces EART-02-003. This document is significantly different to EART-02-003 to reflect changes to ESQCR, BS EN Standards and ENA Technical Specifications
29th Feb 2024	2	Ian Hancock	Revised design and delivery process in line with the new SPEN Distribution Substation Earthing Design Tool. Amendments to the standard earthing arrangements and separation distances. Greater guidance for ICP's and IDNO's. Addition of delivery responsibility matrix, information required for specialist earthing studies and EPR calculation examples.

3. ISSUE AUTHORITY

Authors	Owner	Issue Authority
Name: Ian Hancock Title: Lead Engineer Engineering Design and Standards	Name: Jon Ruiz De Aguirre Title: Substations Manager, Engineering Design and Standards	Name: Fraser Ainslie Title: Head of Engineering Design and Standards F. Ainslie Digitally signed by Fraser Ainslie DN: cn=Fraser Ainslie, o=SPEnergyNetworks, ou=Processes and Technology, email=fraser.ainslie@spenergynetworks.co.uk, c=GB Date: 2024.05.07 11:32:03 +01'00'

4. REVIEW

This is a Reference document which has a 5 year retention period after which a reminder will be issued to review and extend retention or archive.

5. DISTRIBUTION

This document is part of the Construction Virtual Manual maintained by Document Control but does not have a maintained distribution list. This document is also published to the SP Energy Networks website.

6. CONTENTS

7. REFERENCE AND RELATED DOCUMENTS

This specification makes reference to, or implies reference to, the following documents. This document is intended to amplify and/or clarify the requirements of those documents where alternative arrangements are permitted by those documents and/or where further information is required.

It is important that users of all standards, specifications and other listed documents ensure that they are applying the most recent editions together with any amendments. For dated references, only the edition cited applies. For undated references, the edition of the referenced document (including any amendments) valid at the date of issue of this specification applies.

ESQCR	Electricity Safety, Quality and Continuity Regulations
	The Electricity Supply Regulations 1988 (withdrawn – replaced by ESQCR)
BS EN 50522	Earthing of power installations exceeding 1 kV A.C.
BS EN 62305-1	Protection against lightning
BS 7671	Requirements for Electrical Installations. IET Wiring Regulations
ENA TS 41-24	Guidelines for the design, installation, testing and maintenance of main earthing systems in substations
ENA EREC G12	Requirements for the application of protective multiple earthing to Low Voltage networks
ENA EREC S34	A guide for assessing the rise of earth potential at electrical installations
ENA EREC S36	Identification and recording of 'hot' sites – joint procedure for Electricity Industry and Communications Network Providers
ENA EREC S41	Guidance on transferred voltages from earthing systems
ENA TS 37-2	Public Electricity Network Distribution Assemblies
EART-01-002	Low voltage earthing policy and application guide
SWG-03-026	Specification for low voltage fuse boards and network pillars
ENA TS 43-94	Earth rods and their connectors
ENA EREC G88	Principles for the planning, connection and operation of electricity distribution networks at the interface between distribution network operators (DNOs) and independent distribution network operators (IDNOs)
QUAL-12-304	Network Data SAP Input Sheet - Ground Mounted Substation Details

8. DEFINITIONS

For the purpose of this specification, the following definitions shall apply and are reproduced in *italic font* throughout this document:

Backup Protection	Protection set to operate following failure or slow operation of primary protection. (See *Normal Protection* also).
Bonding Conductor	A protective conductor providing equipotential bonding between items of metalwork.
Design Engineer	An engineer who is trained and competent to apply the *Standard Earthing Arrangement* designs contained in this technical specification but is not able to carry out bespoke earthing studies for *Extremely High EPR* or high risk assessments. Typical responsibilities will include, design of distribution substations, overhead lines etc.
Delivery Engineer	A trained and competent engineer whose responsibilities include construction and commissioning distribution substations, overhead lines etc.
Earth	The conductive mass of earth whose electric potential at any point is conventionally taken as zero.
Earth Electrode	A bare conductor or group of bare conductors buried directly in the earth to provide a direct electrical connection with the general mass of earth. This includes earth rods driven into the ground, bare stranded conductors, bare earth tape and mesh.
Earth Electrode Resistance	The resistance of an *Earth Electrode* with respect to *Earth*.
Earth Fault	A fault causing current to flow in one or more earth-return paths. Typically, a single phase to earth fault, but this term may also be used to describe two-phase and three-phase faults involving earth.
Earth Fault Current (I_F)	The worst-case steady state RMS current to earth, resulting from a single phase to *Earth Fault*. Not to be confused with Ground *Return Current* (I_{GR}).
Earth Fault Current (Design)	Fault current used to calculate the size of *Earthing Conductors and Earth Electrodes* based on the system design limit of fault current.
Earth Potential Rise (*EPR*) (or U_E)	The difference in potential which may exist between a point on the ground and a remote *Earth* in the event of an *Earth Fault*. Formerly known as RoEP (Rise of *Earth* Potential).
Earthing Conductor	A conductor connecting the *Main Earth Bar* of an installation to the *Earth Electrode* system or connecting the *Main Earth Bar to* plant and equipment.
Earthing Specialist	A competent earthing designer as determined by knowledge, skills, training and experience such that each earthing design is subject to a technical check and professional review process. Typical responsibilities would include using suitable modelling software to undertake detailed analysis of networks and provide a full bespoke HV/LV earthing design.
Earthing System	The complete interconnected assembly of *Earthing Conductors* and *Earth Electrodes*.
Earth Terminal	*Earth* connection point found on transformers, HV switchgear and LV cabinets / fuse boards which connects to the Main *Earth* Bar.
Effective Radius	The radius of surrounding cable connected network which is effective in providing *Network Contribution*. The *Effective Radius* is dependent on the soil resistivity. Low values of soil resistivity will result in a lower effective radius as all the fault current will flow into the earth before we reach this point. Additional network beyond this radius can be ignored as it has a negligible effect on reducing the *Network Contribution* value any further.
Extremely High EPR	A site with *EPR* exceeding 2.33 kV and requiring special measures (i.e. special design and equipment) to ensure safety. (See section 12.1.3).

Global Earthing System (GES)	An *Earthing System* of sufficiently dense interconnection such that all items are bonded together and all rise in voltage together under fault conditions. No true earth reference exists and therefore *Step Potentials* and *Touch Potentials* are limited.
Ground Return Current (I_{GR})	The proportion of *Earth Fault Current* returning through soil via the general mass of earth.
High EPR	An *EPR* greater than *Low EPR* but not exceeding 2.33 kV. (See section 12.1.2).
Hot / Cold Site	A *Hot* site is defined as one which exceeds *EPR* limits specified in EREC S36. For secondary substations sites (with long clearance times), if the *EPR* exceeds 430 V then it shall be classified as a *Hot Site*.
Low EPR	The upper limit of *Low EPR* will be determined by the type and extent of the low voltage network the new substation supplies. For the purposes of this document, this is defined as an *EPR less than or* equal to 430 V for substantial new PME networks (such as a new housing estate with multiple earth electrodes) or less than or equal to 233 V for new SNE networks. (See section 12.1.1).
Main Earth Bar	The Main *Earth* bar provides a recognised earth connection / reference point which is connected to the earth terminals and serves the purpose of allowing the local substation earth resistance to be measured using a clamp meter as well as helping operational personnel to determine if the earthing is intact when entering a substation.
Maximum Permissible Touch Potential (U_{Tp})	The maximum permissible *Touch Potential* related to the appropriate HV fault clearance time *(ENA TS 41-24: 9.5.2 Touch potential on LV system as a result of an HV fault).*
Network Contribution	The *Earth Electrode* effect of the wide area HV (and LV) interconnected network. Large networks provide multiple parallel *Earth Electrodes* which can provide a relatively low resistance path to earth. (See section 10.9).
Normal Protection	Clearance of a fault under normal circumstances. This includes relay operating time and circuit breaker opening time for all foreseeable faults. This time assumes that faults will be cleared by normal upstream protection and does not allow for e.g. stuck circuit breakers or other protection failures / delays.
SPEN Distribution Substation Earthing Design Tool	A macro enabled Microsoft EXCEL workbook to assist *Design Engineers* to determine if *Standard Earthing Arrangements* are appropriate. (See section 13.1.3).
Standard Earthing Arrangement	These are standard designs of typical ground-mounted substations and pole-mounted installations used in SPEN with a pre-designed layout of *Earthing System.* The *Step* and *Touch Potentials* (as a % of *EPR* for each standard layout) have already been established by modelling or calculation.
Step Potential (U_S)	Voltage between two points on the ground surface that are 1 m distant from each other where 1 m is considered to be the stride length of a person. (See section 10.4).
Stress Voltage	Voltage difference between two segregated *Earthing Systems*, which may appear) across insulators/ bushings or cable insulation etc. (See section 10.6).
Target Resistance	The resistance of the substation local *Earth Electrode* system determined by policy or design. (See section 10.8).
Touch Potential (U_T)	Voltage appearing between a person's hands and feet, or across both hands when conductive parts are touched simultaneously. (See section 10.3).
Transfer Potential	Potential transferred by means of a conductor between an area with a significant *EPR* and an area with little or no *EPR* and results in a potential difference between the conductor and earth in both locations. (See section 10.5).

9. FOREWORD

This document has been revised to reflect significant changes in legislative and industry standards and specifications relating to earthing and changes in equipment types currently employed. The main changes that have led to the revision of this specification include:

i. Changes to earthing practices as outlined in Electrical Safety, Quality, and Continuity Regulations (ESQCR), in particular, with regard to secondary substations.

ii. UK Adoption of BS EN 50522, in particular with reference to acceptable *Touch Potential* and *Step Potential* limits.

iii. Revision of ENA TS 41-24 that reflect changes to earthing practice for alignment with BS EN 50522.

iv. Changes to the requirements for Protective Multiple Earthing systems (PME) as outlined in ENA EREC G12.

v. The extensive use of plastic sheathed cables as compared to lead sheath cables.

9.1 Legacy Practice for Earthing at Secondary Substations

For ground-mounted substations, the legacy practice in SPEN (and other DNOs) was to install HV and LV *Earthing Systems* with an HV *Earth Resistance* of 40 Ω and an LV *Earth* Resistance of 20 Ω.

If the combined *Earth Resistance* of the HV and LV *Earthing Systems* (including *Network Contribution* from HV and LV cable sheaths) was less than 1 Ω, then it was permissible to combine the HV and LV *Earthing Systems*. The “1 Ω Rule” practice was based on the requirements of The Electricity Supply Regulations 1988.

No perimeter *Earth Electrodes* were installed around the substation. This approach relied heavily on contributions from PILC cables radiating away from the substation, often passing under the operator’s position. Since the lead sheath and steel armour/tapes of the cable are in contact with the ground (even where hessian servings are used), these cables provided a degree of potential grading (thus reducing *Touch Potentials*) as well as reducing the combined earth resistance of the substation.

9.2 Modern Practice for Design of Earthing at Secondary Substations

The Electricity Supply Regulations, 1988 were replaced by the ESQCR in 2002 and the legacy “1 Ω Rule” is no longer relevant.

The ESQCR state that the owner of the HV network shall ensure that, “the earth electrodes are designed, installed and used in such a manner to prevent danger occurring in any low voltage network as a result of any fault in the high voltage network”.

BS EN 50522 provides criteria for design, installation, testing and maintenance of *Earthing Systems* of electrical power installations with nominal voltage above 1 kV. This standard is applicable to substations and pole/tower installations and requires that the installation operates safely under all conditions and ensures the safety of human life in any place to which persons have legitimate access.

ENA TS 41-24 was revised in November 2018 to reflect the changes to earthing practice as outlined in ESQCR and to align with BS EN 50522. This recognises that the “1 Ω Rule” no longer fully complies with UK standards so this practice has now been withdrawn.

The requirements of this specification are based on compliance with the latest issues of ESQCR, BS EN 50522, ENA TS 41-24 and ENA EREC S41.

9.3 Standard Earthing Arrangements

The approach used by this specification is based on the adoption of "*Standard Earthing Arrangements*" wherever possible. The standard designs for ground mounted substations have been evaluated to ensure a *Touch Potential* of no greater than 10% of EPR is experienced during an HV fault. *Standard Earthing Arrangements* showing the *Earthing System* to be installed at typical ground-mounted substations and pole-mounted installations are given in section 15.

This process allows the *Design Engineer* to choose a SPEN *Standard Earthing Arrangement* based on particular scenarios such as substation location, system fault levels and *Network Contribution*. It is anticipated that this procedure will be appropriate for the vast majority of situations.

However, there will be some situations where *Standard Earthing Arrangements* are not suitable and a detailed study shall be carried out by an *Earthing Specialist*.

10. INTRODUCTION

An *Earthing System* shall be installed at every substation and designed so that there is no danger to persons.

The *Earthing System* shall be designed to avoid damage to equipment due to excessive potential rise and potential differences within the *Earthing System* and due to excessive currents flowing in auxiliary paths not intended for carrying *Earth Fault Current*.

The term "*Earthing"* generally describes connection to the general mass of earth using a dedicated *Earth Electrode*. The related term, '*Bonding*", means connecting items together so they are at equal potential. A well-designed *Earthing System* provides both *Earthing* and equipotential *Bonding*.

The main functions of an *Earthing System* are to:

i. Limit the voltage rise (and voltage differences) on exposed metalwork under fault conditions so as to reduce risk of shock to operators and members of the public who might be nearby.
ii. Ensure that any *Earth Fault Current* is carried safely back to the source substation without causing damage to any equipment such that system protection operates quickly.

Additionally, for secondary substations, the *Earthing System* serves to:

i. Prevent dangerous potentials appearing on the customers' LV neutral/earth terminals.
ii. Comply with the requirements for substation LV earthing described in ENA EREC G12 and EART-01-002.

10.1 *Earth Fault Current*

In case of a fault directly to earth, *Earth Fault Current* will flow. A path is required to allow sufficient *Earth Fault Current* to flow back to its source (i.e. the Primary substation). This allows system protection to operate and disconnect the supply. This current will cause heating in all conductors which form a path for the *Earth Fault Current.* An important part of the path is the buried *Earth Electrode* at the substation which will be required to carry part (or all) of the *Earth Fault Current*.

The *Earthing Conductors* and *Earth Electrodes* shall be able to withstand the maximum expected *Earth Fault Current* as described in section 11.1.

10.2 *Earth Potential Rise (EPR)*

During the passage of *Earth Fault Current,* the substation buried *Earth Electrode* will be subjected to a rise in voltage. This is called *Earth Potential Rise* (*EPR*) and is dependent on the magnitude of *Earth Fault Current* in combination with the *Earth Electrode Resistance.*

Potential gradients develop in the surrounding ground area and these are highest adjacent to the *Earth Electrode*. The *EPR* reduces to approximately zero (or true earth potential) at some distance from the *Earth Electrode*. Figure 1 shows the potential gradient caused by an *EPR* (where one *Earth Electrode* is installed).

The ESQCR require that danger will not arise on the LV system as a consequence of HV faults. If the HV and LV *Earthing Systems* are connected, in event of HV *Earth Faults*, the resultant *EPR* will be impressed on the LV neutral / earth (secondary transformer star point) and this voltage will ultimately be transferred to a customer's LV earthing terminal. To avoid this danger, the HV and LV *Earthing Systems* shall be separated if the *EPR* exceeds particular limits. (These limits are given in section 12).

The three main design parameters relating to the consideration of *EPR* when designing a substation *Earthing System* are:

i. *Touch Potential,*
ii. *Step Potential* and
iii. *Transfer Potential.*

A person could be at risk if they can simultaneously contact parts at different potential, thus, in a well-designed system, the potential differences between metallic items shall be kept to safe levels regardless of the level of *EPR*.

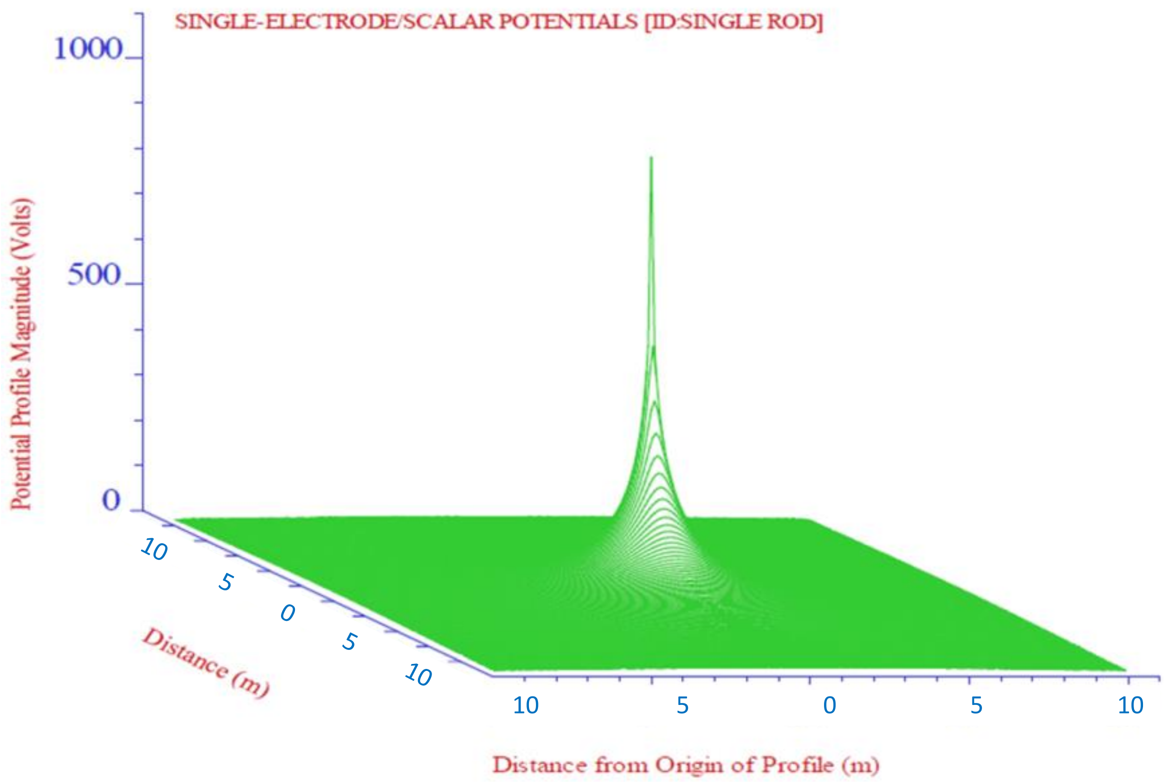


Figure 1 – Potential Gradient due to *EPR* (with Single *Earth Electrode*)

10.3 *Touch Potential*

This term describes the voltage appearing between a person's hands and feet, or across both hands. Hand to foot *Touch Potential* arises from the fact that the *EPR* at a person's hands can be somewhat higher in value than that present at their feet. If an earthed metallic structure is accessible, a person standing on the ground and touching the structure will be subject to a *Touch Potential*. This is demonstrated in Figure 2.

The limits for *Touch Potentials* are given in section 12.1.4.

The value of *Touch Potentials* is not only influenced by the *EPR* but also depends on the arrangement of the *Earthing System* and buried *Earth Electrodes*. By comparing the *EPR* gradients in Figure 2 and Figure 3, represented by the blue line in each, it can be seen that the action of installing a perimeter *Earth Electrode* buried around the substation (Figure 3) significantly reduces the potential gradient of the *EPR* (i.e. kV/m) compared to an installation utilising an *Earth Electrode* buried at a single point (Figure 2). This solution reduces the maximum *Touch Potential* that staff (and members of public) may be exposed to.

Hand-to feet *Touch Potentials* can be further reduced by installing an *Earth Electrode* bonded to the HV metalwork and buried at a relatively shallow depth immediately below the position that the operator will stand when operating HV switchgear or other plant. This is often referred to as a "*Earth* mat" or "Stance Earth".

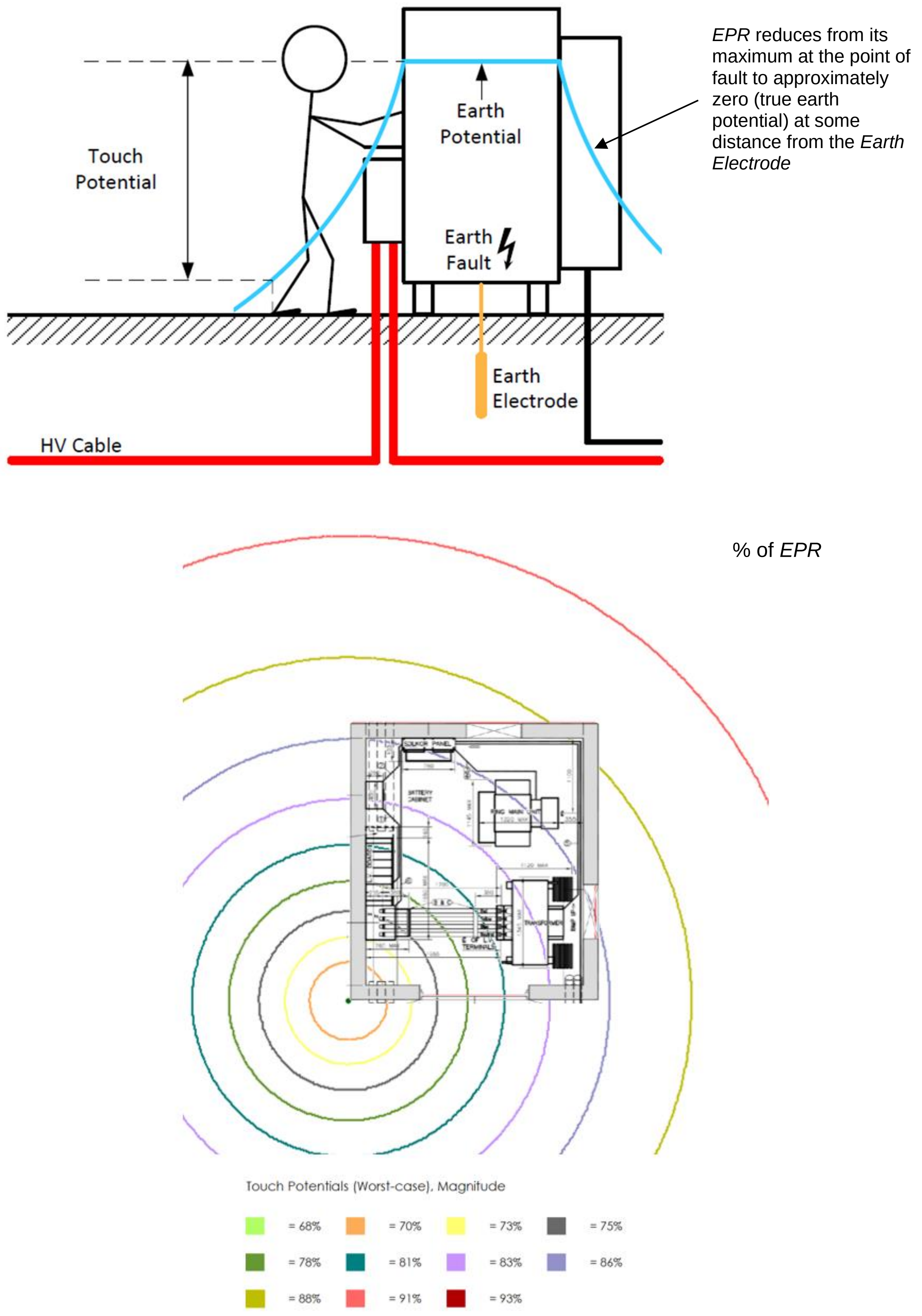


Figure 2 – *Touch Potential* Gradient (Single *Earth Electrode*)

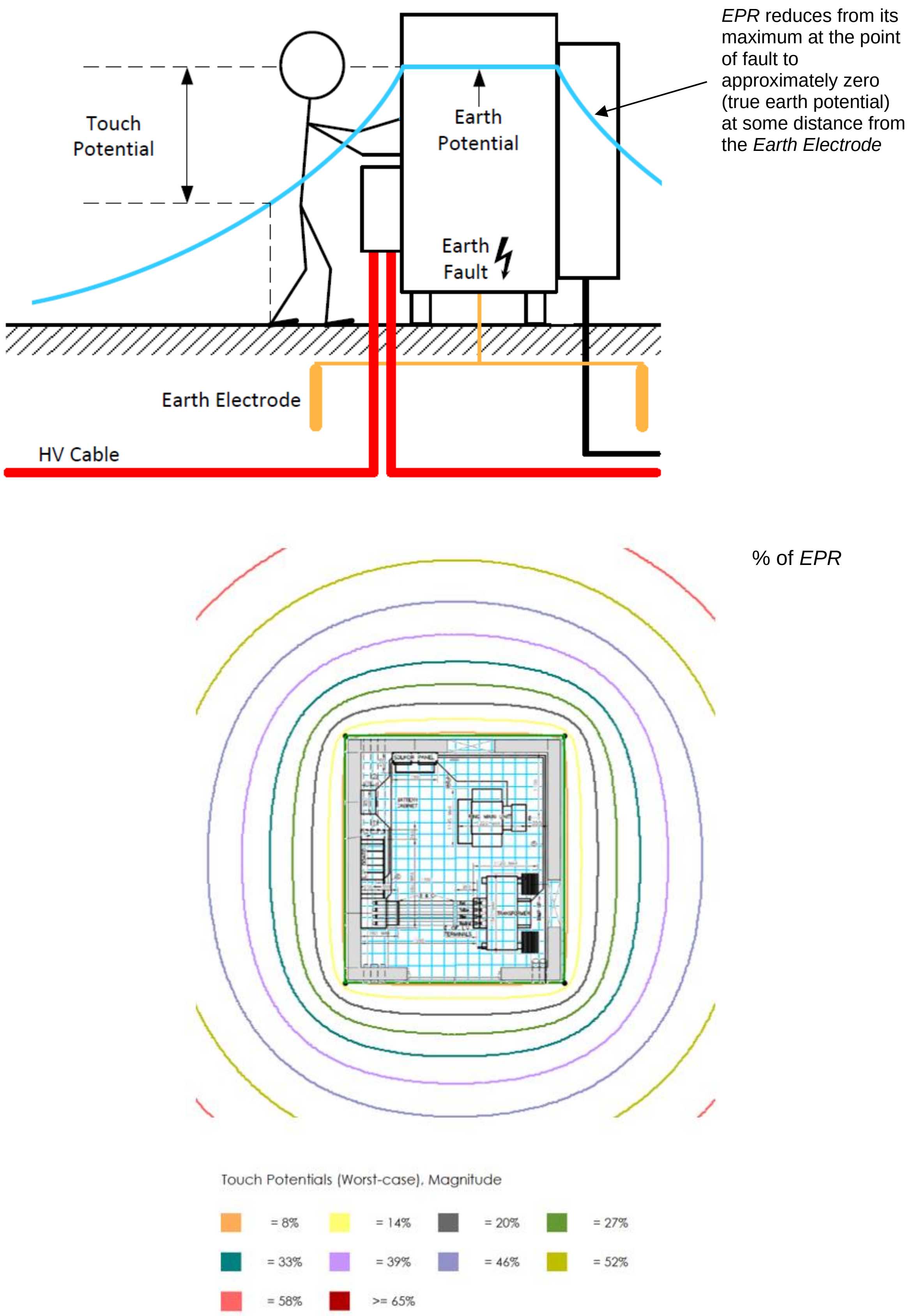


Figure 3 – *Touch Potential* Gradient (Perimeter *Earth Electrodes* Around Substation)

10.4 *Step Potential*

This term describes the voltage between two points on the ground surface that are 1 m distant from each other (which is considered to be the stride length of a person). The potential gradient in the ground is greatest immediately adjacent to the buried *Earth Electrode* so the maximum *Step Potential* will be experienced by a person who has one foot on the ground of maximum *EPR* and the other foot one step towards true earth.

The permissible limits for *Step Potential* are usually much higher than for *Touch Potential*. As a consequence, if a substation is safe against *Touch Potential*, it will normally be safe against *Step Potentials*.

Figure 4 shows an example where staff or public can be exposed to *Step Potentials.*

The limits for *Step Potentials* are given in section 12.1.5.

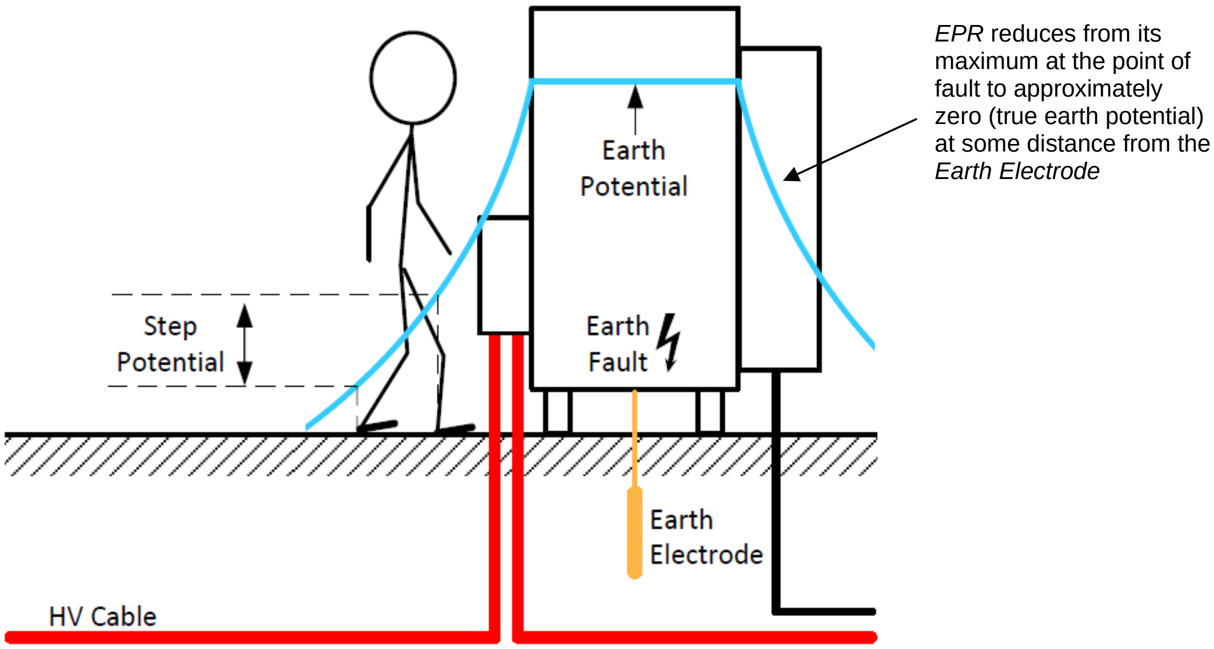


Figure 4 – Example of *Step Potential*

10.5 *Transfer Potential*

A metallic object having some length (e.g. fences, pipes or cables) may import or export a potential into or out from the site. By such means a remote, or true earth (zero potential) can be transferred into an area of *High EPR* or vice-versa. This is called *Transfer Potential.*

For example, a long metal substation fence may export *EPR* out of the site to the end of the fence, where it may pose an electric shock hazard to somebody standing on soil at true earth potential. Similarly, a metallic water pipe or cable may import a zero-volt reference into a substation, where local potential differences may be dangerous. Bonding the cable or pipe to the substation *Earthing System* may reduce risk in the substation but may create a problem elsewhere. Isolation units or insulated inserts are typical solutions that may need to be considered. Figure 5 shows an example of the risks associated with *Transfer Potential*.

In secondary substations, the consideration of *Transfer Potentials* is particularly important given that LV neutral/earth conductors may be connected to, or close to, HV *Earthing Systems* or other LV *Earthing Systems*, and consequently these conductors could export a *Transfer Potential* in to customer installations (e.g. on to a customer's LV earthing terminal).

The limits for permissible *Transfer Potential* relate to shock risk (*Touch Potential* and *Step Potential*) and are given in sections 12.1.4 and 12.1.5.

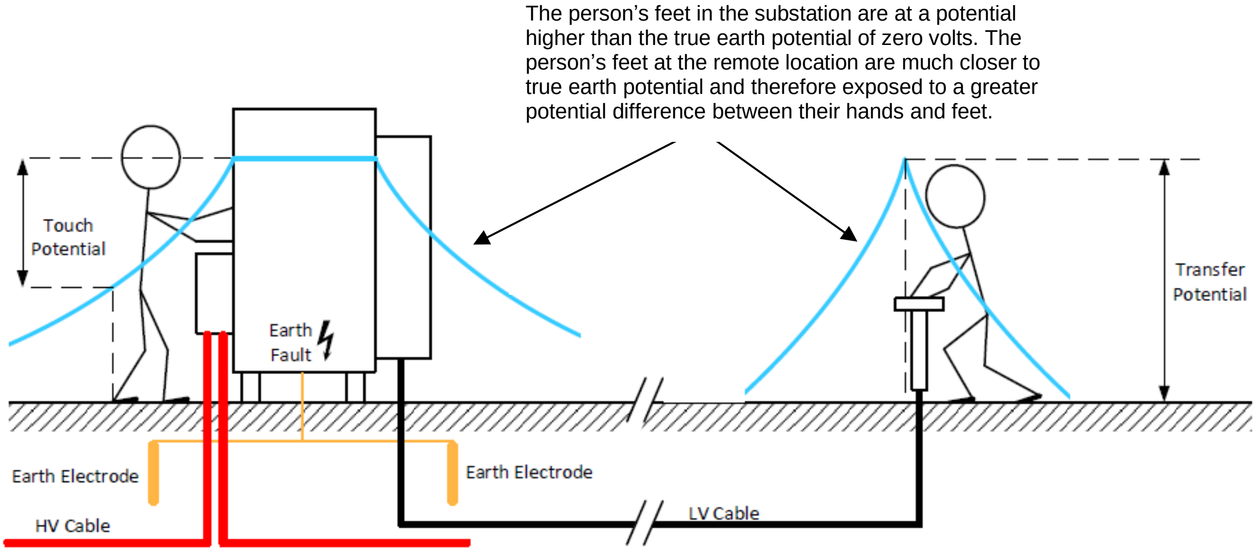


Figure 5 – Example of Risk of *Transfer Potential* (Cable Installed from Substation to Remote Location)

10.6 *Stress Voltage*

A further consideration relating to magnitude of *EPR* is "*Stress Voltage*". The *Stress Voltage* is the voltage which appears across any two points in a substation or connected circuits (e.g. voltage between two *Earthing Systems*).

If HV and LV *Earthing Systems* are combined, *Stress Voltage* limits are unlikely to be exceeded in the substation. If the HV and LV *Earthing Systems* are segregated, then the *Stress Voltage* includes the difference in potential between the HV and LV *Earthing Systems* and may be assumed equal to the *EPR* of the substation.

The limits for *Stress Voltage* and typical equipment that may be exposed to this voltage are described in section 12.1.6.

10.7 Equipment Bonding

Any exposed, normally un-energised metalwork, within a substation may become live by consequence of a system insulation failure so can present a safety hazard to personnel. It is a function of the *Earthing System* to eliminate such hazards by solidly bonding together all such metalwork

All normally accessible metalwork within a substation is connected together and to the *Main Earth Bar*, using a *Bonding Conductor (*or *Earthing Conductor*). This is to ensure that all adjacent, exposed metalwork remains at a similar potential during fault conditions.

The size of *Bonding Conductors* that shall be employed is given in sections 15.1 and 15.2.

10.8 *Target Resistance*

For normal (typical) network scenarios, the approach taken by SPEN in this specification for designing the *Earthing System* is to use *Standard Earthing Arrangements* (see section 15). Then, provided certain conditions are met, specified values of the local substation *Earth Electrode Resistance* can be utilised that will provide compliance with voltage limits for *Step* and *Touch Potentials*. The resistance specified for each case is termed "*Target Resistance".*

The *Target Resistance* is the measured resistance that must be achieved when the buried *Earth Electrode* system has been installed at the secondary substation being considered**.** This is the resistance without any *Network Contribution.* (Section 10.9 describes the effect of *Network Contribution* which may be provided from interconnected substations cables etc.)

This approach is intended to minimise calculation effort, based on normal (typical) scenarios. By employing the *Target Resistance* approach, the local HV *Earth Electrode* system for the substation shall have a sufficiently low resistance to ground to ensure reliable operation of the circuit protection and to limit the *EPR* (and consequently *Touch* and *Step* potentials) to acceptable levels. This technique is useful as it is a readily understood parameter that can be achieved and tested by installers of the *Earthing System*.

10.9 *Network Contribution*

In urban areas in particular, the substation may be interconnected to many other substations by an underground cable network and these substations can have the effect of reducing the overall HV network earth resistance (R_B). The effect from the rest of the HV network on the overall HV network earth resistance is termed "*Network Contribution"* and is a very important consideration when calculating the substation *EPR*.

Once the HV cable sheaths / screens are connected to the substation local *Earth Electrode*, the overall substation HV earth resistance will be reduced because any remote *Earthing Systems* from the underground distribution network contribute in parallel with the substation local *Earth Electrode*. Large networks provide multiple parallel electrodes which can provide a relatively low resistance path to earth and the *Network Contribution* can be significant (i.e. providing a low resistance). A representation of how interconnected secondary and primary substations (with parallel connected *Earth Electrodes*) provide a *Network Contribution* that results in a lower overall HV network earth resistance is shown in

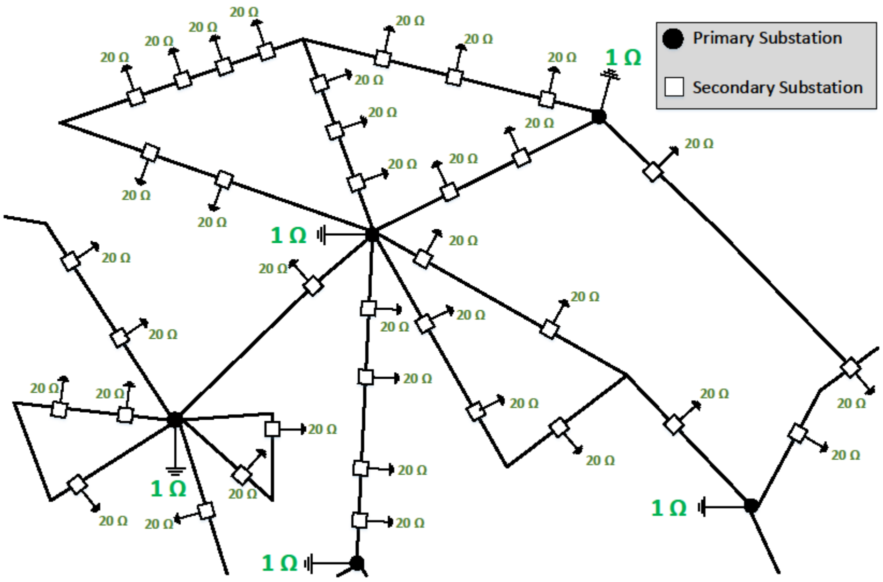


Figure 6 – *Network Contribution* from Interconnected Secondary and Primary Substations

In case of pole-mounted installations, it can generally be assumed that there will be no *Network Contribution* and consequently no reduction in the overall HV network earth resistance. Therefore, the *EPR* is calculated from the local *Earth Electrode Resistance* only (i.e. the local *Earth Electrode* system installed at that particular pole-mounted substation). This can also be the case for ground-mounted substations which are fed from overhead line networks and depends if other secondary substations are connected to the same section of HV cable as the substation being considered.

10.10 *Global Earthing System* (GES)

A *Global Earthing System (GES)* is defined as "An *Earthing System* of sufficiently dense interconnection such that all items that are bonded together rise in voltage simultaneously under fault conditions. No true earth reference exists and therefore safety voltages are limited".

In a *GES,* the ground is saturated with metallic electrode contributions in the form of LV and HV *Earthing Systems*, metallic cable sheaths or bare conductors (e.g. pipes) laid direct in soil. In such a system, the soil surface potential will rise in sympathy with that of bonded steelwork under fault conditions. The equivalent *Earthing System* created by the interconnection of local *Earthing Systems* ensures that there are no dangerous *Touch Potentials.* Essentially this is the premise of *Network Contribution*.

Networks within a *GES* by definition operate with combined HV /LV *Earthing Systems*.

Typical examples where a *GES* exists are:

i. Substations feeding city centre or densely built up areas with distributed low and high voltage *Earthing Systems*.
ii. Substations feeding suburban area with many distributed *Earth Electrodes* interconnected by protective conductors of low voltage system.
iii. Substation with a large number of nearby substations.

A representation of a *GES* is shown in Figure 7, where it can be seen that there is a large urban area with multiple substations (and associated *Earth Electrodes*) interconnected by underground cables offering a low resistance *Network Contribution*.

Section 10.9 describes how *Network Contribution* is considered and explains the impact of interconnected primary and secondary substations.

Figure 7 – Example of a *Global Earthing System (GES)*

11. FAULT CURRENTS APPLICABLE TO DESIGNS OF EARTHING SYSTEMS

This section outlines the values of *Earth Fault Current* that shall be used when designing an *Earthing System*. These are summarised in Table 1 and explained in detail in the relevant sub sections.

Design Criteria	Earth *Fault Current and duration*	Document section
Functional Requirements Rating of *HV Earthing Conductors* and HV *Earth Electrodes*	Maximum HV System *Earth Fault Current (Design)* *Backup Protection* operation time of 3 s	11.1
Safety Requirements Calculation of EPR Levels for *Touch* and *Step Potentials*	*Ground Return Current* (I_{GR}) based on % of maximum *Earth Fault Current* calculated for faults at the node point for secondary substation. *Normal Protection* operating time of 1 s	11.2

Table 1 – *Earth Fault* Currents to be Employed in Calculations

The *Earthing System* shall remain intact and be able to pass the maximum *Earth Fault Current* at any fault location back to the system neutral. The design of the *Earthing System* shall ensure that the passage of this *Fault Current* does not result in any thermal or mechanical damage to conductors or insulation and facilitate correct operation of the source circuit-breaker. These are the functional requirements of an *Earthing System*.

Additionally, the *Earthing System* shall be able to pass *Earth Fault Current* whilst maintaining *Touch Potentials* and *Step Potentials* within the permissible limits defined in sections 12.1.4 and 12.1.5. This is also a functional requirement of an *Earthing System.*

11.1 Functional Requirements (Ratings of *HV Earthing Conductors* and *Earth Electrodes*)

BS EN 50522 requires that "The *Earthing System*, its components and *Bonding Conductors* shall be capable of distributing and discharging the fault current without exceeding thermal and mechanical design limits based on *Backup Protection* operating time".

All above ground HV *Earthing Conductors* and buried HV *Earth Electrodes* shall be capable of carrying the maximum HV System *Earth Fault Current (Design),* based on the *Backup Protection* operation time, without any damage (i.e. the design shall take account of possible failure of the primary protection system). The HV System *Earth Fault Current (Design)* levels that shall be used when selecting the rating of HV *Earthing Conductors* are given in Table 2.

The buried *Earth Electrode* shall retain its functional properties at all times (i.e. both its current carrying capability and its value of resistance to earth). For these reasons, the temperature rise of the *Earth Electrode* and the density of current dissipation to the soil, during the passage of *fault current*, needs to be considered. Thermal requirements are satisfied by appropriate choice of conductor material and cross-sectional area. Surface current density requirements are satisfied by ensuring sufficient surface area of the buried *Earth Electrode.*

Note	Situation	HV System *Earth Fault Current* (Design)	Fault duration
i	Ground-mounted	13.1 kA	3 s
ii	Pole-mounted	4 kA	3 s
iii	Pole-mounted	8 kA	3 s

Table 2 – HV *Earth Fault Current (Design)* Levels Used to Calculate Size of HV *Earthing/Bonding Conductors* and *Earth Electrodes*

Notes:

i. At ground-mounted secondary substations, the HV *Earthing Conductor* and buried HV *Earth Electrode* shall be able to withstand the HV System *Earth Fault Current (Design)* level of 13.1 kA for a duration of 3 seconds. This shall include rural and urban locations.

ii. At pole-mounted secondary installations, an HV System *Earth Fault Current (Design)* level of 4 kA for a duration of 3 seconds shall generally be employed for the vast majority of pole-mounted sites in SPEN. This is based on these largely being situated in rural locations with low fault levels and the relatively large impedance on overhead line conductors. The *Design Engineer* shall calculate the fault level at the location to determine that fault level does not exceed this value.

iii. In cases where pole-mounted secondary installations are installed close to Primary Substations, or at locations where the *Earth Fault Current* may exceed 4 kA, an HV System *Earth Fault Current (Design)* of 8 kA shall be employed.

11.2 Safety Requirements (Calculation of *EPR* for *Touch Potentials* and *Step Potentials)*

An effective *Earthing System* is essential to ensure the safety of persons in, and close to substations, and to minimise the risk of danger on connected systems beyond the substation boundaries. The most significant hazard to humans is that sufficient current may flow through the heart to cause ventricular fibrillation. The basic criteria adopted in this specification for the safety of people are those prescribed in BS EN 50522.

The design of the *Earthing System* shall comply with the safety criteria (*Touch* and *Transfer Potentials*) which are a function of *Earth Fault Current* and fault duration.

11.2.1 Earth Fault Current used to Calculate EPR Level

The *Earth Fault Current* used to calculate the *EPR* level for *Touch Pote*ntials and *Step Potentials* is the maximum steady state *Earth Fault Current* that the installation will experience under fault conditions. This is the prospective single-phase to earth (line to ground) RMS fault current at 90 ms that has been calculated for faults at the secondary substation HV busbar. Consideration shall be given to future network alterations and alternative running arrangements. A margin should be added to allow for future changes without detailed assessment (e.g. typical 15% increase, unless more accurate information is available).

Note: In most cases this is likely to be lower than the maximum system fault level used to calculate the rating of *HV Earthing Conductors* and *Earth Electrodes.* This will result in a more realistic assessment of *EPR.*

11.2.2 *Ground Return Current*

Where secondary substations are connected to a primary substation via underground cables with no overhead line sections between the primary and the secondary substation, the cable screen/sheath provides a metallic return path for the *Earth Fault Current.*

The remainder of *Earth Fault Current* will return through soil to the neutral connection at the primary substation. Further guidance is given in ENA EREC S34. Only the component of *Earth Fault Current* returning to source via the *Earth Electrode* into the soil is used to calculate the *EPR.* This called the *Ground Return Current* (I_{GR}) and is a fraction of total *Earth Fault Current* (I_F).

For complete underground cable networks between primary and secondary substation, 30% of the *Earth Fault Current* is assumed to return to primary through the soil (i.e. I_{GR} = 30 % x I_F). If any overhead line is introduced, or other measures to break sheath continuity, I_{GR} will be 100% of I_F.

12. EPR LEVELS AND LIMITS FOR STEP AND TOUCH POTENTIALS

The design of the *Earthing System* must comply with the safety limits for *Touch Potential* and *Step Potential* along with insulation withstand between different systems which will tend to restrict the acceptable level of *EPR.* Where the *EPR* exceeds the *Stress Voltage* of equipment then mitigation is required in the form of recognised specific and additional measures.

For pole-mounted transformers, the HV metalwork is placed out of reach to ensure that staff and public are not exposed to hazardous *Touch Potentials* so a *High EPR* can be tolerated on the HV steelwork. Additionally, the LV *Earth Electrode* system is separated from the HV *Earth Electrode* system to avoid potentially dangerous voltages being transferred to a customer's LV earthing terminal.

In case of ground-mounted substations, the design of the *Earthing System* shall ensure that *Touch and Step Potentials* are acceptable. These are ultimately some fraction of *EPR.* The *EPR* for a secondary substation is calculated in the conventional manner by multiplying the *Ground Return Current* (I_{GR}) by the overall HV network earth resistance (R_B). $EPR = I_{GR} \times R_B$.

The overall HV network earth resistance (R_B) shall include the reduction in resistance provided by the *Network Contribution* (if any) from the underground distribution network in parallel with the substation *Earth Electrode*.

Touch Potential and Step Potential limits are dependent on the fault duration and hence the total fault disconnection time including protection and circuit breaker operation. The additional foot contact resistance presented by different types of surfaces (e.g. soil, concrete, etc.), will also effect the limits.

Permissible touch potential limits for typical HV fault clearance times and a range of situations / surface conditions are stated in Table 1 of ENA TS 41-24. For definitions of EPR which follow in this document, a standard clearance time of 1 second applies and a scenario of a person wearing shoes on soil or outdoor concrete has been used. The fault duration used when considering acceptable *EPR* levels, shall be the *Normal Protection* operating time of 1 s, rather than slow *Backup Protection* operation clearance time of 3 s. This is in accordance with guidance given in ENA TS 41-24 to meet safety criteria.

12.1.1 *Low EPR*

In the case of a person wearing shoes on soil or outdoor concrete and an HV fault clearance time of 1 s, *Low EPR* is defined in Table 1 of ENA TS 41-24 as an *EPR* ≤ 233 V.

However, BS EN 50522 introduces the concept of an F-factor which relates to the percentage of EPR that will appear as a *Touch Potential* on the LV network. It also relates to the potential grading that will occur within an installation and the decay in exported potential along a multiple earthed neutral conductor. HV and LV earthing systems shall only be combined if the EPR does not exceed $F \times U_{Tp}$, where U_{Tp} is the permissible *Touch Potential* related to the appropriate HV fault clearance time *(ENA TS 41-24:* clause *9.5.2 Touch potential on LV system as a result of an HV fault)*. A value of F=1 shall be used unless new customers are fed from a substantial PME network such as a new housing estate with multiple earth electrodes. Where a substantial PME network exists then a value of F=2 shall be used.

This leads to a changeable definition of *Low EPR* which depends on the F factor applied. For an F-factor of 2, the upper *Low EPR* limit becomes 466 V rather than 233 V.

Additionally, ENA EREC S36 sets thresholds for maximum *EPR* to ensure that telecommunications and other systems are not adversely impacted by substation *EPR*. For secondary substations (i.e. with long clearance times), the *EPR* must be limited to 430 V to be considered as a "*Cold Site".* Otherwise special precautions must be employed.

The terms "Hot" and "Cold" have been used in the past as a convenience (on the basis that many "Cold "sites will achieve safe step/touch limits) but do not relate directly to safe design limits for *Touch Potentials* and *Step Potentials* in substations. Modern standards refer to *High EPR* and *Low EPR* sites in an attempt to move away from the reliance on third party / telecommunications standards, and so the terms *Hot Sites* and *Cold Sites* are not used in this document.

For simplicity and interchangeability with what are termed "*Cold Sites*" in ENA EREC S36, SPEN has decided to utilise 430 V as a limit for *Low EPR* sites where the F-factor is 2 to provide an additional margin of safety whilst still complying with telecoms requirements.

Table 3 summarises some *Low EPR* limits for an F-factor of 1 and 2.

Situation/ Surface condition	Maximum Touch Potential (U_{Tp})	Low EPR Limit (F-factor = 1)	Low EPR Limit (F-factor = 2)
Shoes on soil or outdoor concrete	233 V	233 V	430 V
Shoes on 75 mm chippings	259 V	259 V	518 V
NOTES: The values of maximum touch potential are taken from Table 1 of ENA TS 41-24 for an HV fault clearance time of 1 second. Barefoot scenarios are applicable for some situations outside substation areas; refer to section 14 (special situations).			

Table 3 – Maximum Permissible *Touch Potential* (U_T)

Where reasonably practicable, the *EPR* at ground-mounted sites shall be limited to *Low EPR*, in which case the HV and LV *Earthing Systems* can be combined. Figure 8 shows a typical example of the link used to interconnect the HV steelwork earth (LV cabinet frame earth) and LV Neutral bar inside the LV cabinet in a close coupled GRP substation. The link is shown in its closed position which acts to combine the HV and LV earthing systems together.

Figure 8 – Typical HV/LV Link Inside LV Cabinet (Link in Closed Position)

In some high risk sites the touch potential limit and consequently the maximum EPR can be substantially less for a 1 s HV protection clearance time as a person subjected to a touch potential may not be wearing shoes on soil or outdoor concrete. For example, in the case of a swimming pool where people will be barefoot in wet areas, the maximum permissible touch potential limit is 80 V. In these cases, a specialist study must be undertaken.

12.1.2 *High EPR*

For the purpose of this document *High EPR*, is defined as an *EPR* greater than the relevant *Low EPR* limit defined above but not exceeding 2.33 kV.

For ground-mounted substations where the EPR is classified as high, the HV and LV *Earthing Systems* shall be segregated.

In the case of ground-mounted substations, segregation of the HV and LV *Earthing Systems* is achieved by opening the HV/LV Earthing link inside the LV cabinet. If this link is removed, a separate LV earthing electrode is required. The LV *Earth Electrode Resistance* shall not exceed 20 Ω in accordance with EART-01-002.

12.1.3 *Extremely High EPR*

For the purpose of this document an *Extremely High EPR,* is defined as an *EPR* greater than 2.33 kV.

In the case of pole-mounted installations or ground-mounted substations which are fed from overhead lines there will be no benefit of cable sheath/screens for a proportion of *Earth Fault Current* to return to the source Primary substation. Therefore, the *EPR* may approach the system phase-earth voltage. *Extremely High EPR* is defined in this specification as an *EPR* greater than 2.33 kV.

An upper limit to *EPR* is imposed by the dielectric withstand provided by insulation (and/or physical separation) between the HV and LV *Earthing Systems* (i.e. *Stress Voltage*). This withstand capability ensures that the LV *Earthing System* remains insulated from HV steelwork when the HV steelwork is raised to an elevated potential during fault conditions. The limiting factor can be the insulation inside the LV cabinet, transformer LV bushings, or the transformer windings themselves. The insulation on this equipment experiences a voltage stress under HV fault conditions. See section 12.1.6 regarding limits for *Stress Voltage.*

If the *EPR* at ground-mounted substations exceeds 2.33 kV, then the HV and LV *Earthing Systems* shall be segregated and a specialist earthing study shall be carried out.

Additional precautions shall also be taken at these sites, particularly where LV supplies are brought into the substation. (See sections 14.2 and 15.8.4).

12.1.4 *Touch Potential* Limits

Touch Potential is calculated by multiplying the *EPR* by a % value which is based on the design of the substation *Earthing System*. This % multiplier is influenced to a small degree by the depth of the *Earth Electrode* and the proximity of other earthed metalwork, but for design purposes can be taken as fixed for each layout.

The limits for *Touch Potentials* are set out in ENA TS 41-24 and are summarised in Table 3 for a 1 s HV clearance time and a soil or outdoor concrete surface. In operational areas it can be assumed that people are wearing shoes. Therefore, based on a 1 s clearance time, and for substations with outdoor concrete, a maximum *Touch Potential* of 233 V is appropriate.

12.1.5 *Step Potential* Limits

The limits for *Step Potentials* are summarised in Table 4 – *Step Potential* Limits . The limits for *Step Potential* have been recently revised in national standards and are now much higher than previously. As a result, compliance with *Touch Potential* in Table 3 will almost certainly provide acceptable *Step Potentials* in and around the substation for individuals wearing footwear.

Situation/ Surface condition	Maximum *Step Potential*
Shoes on soil or outdoor concrete	17.5 kV
NOTE: As for *Touch Potential*, these limits are calculated according to fibrillation thresholds. Immobilisation or falls / involuntary movements could occur at lower voltages. In general, compliance with *Touch Potential* limits will achieve safe *Step Potentials*.	

Table 4 – *Step Potential* Limits

12.1.6 *Stress Voltage* Limits

In cases where the HV and LV *Earthing Systems* are segregated, the *Stress Voltage* between the HV and LV *Earthing Systems* can be assumed to approach the *EPR* of the substation.

The limits for *Stress Voltage* are based on the insulation withstand of the HV and LV equipment employed in the substation. The insulation withstand levels of this equipment must be adequate to ensure that, in the event of an HV fault in a *High EPR substation*, the insulation does not breakdown causing the *EPR* on the HV *Earthing System* to be transferred to the LV *Earthing System.*

For *High EPR* ground-mounted substations where the HV and LV *Earthing Systems* have been segregated, the *EPR* will not exceed 2.33 kV and it is unlikely that *Stress Voltage* limits will be exceeded.

For pole-mounted substations and in ground-mounted substations with *Extremely High EPR*, the *EPR* (and consequently the *Stress Voltage* imposed on the insulation of HV and LV equipment) may approach the system phase-earth voltage (i.e. 6.35 kV for 11 kV system). The *Design Engineer* shall ensure that the equipment employed in these installations is suitable for this application. Any new equipment purchased by SPEN is rated to 7 kV. Historically this may not be the case (see notes in Table 5 below).

The typical equipment that may be exposed to a *Stress Voltage* in event of an *Earth Fault* at a secondary substation and the insulation withstand limits that apply to this equipment is listed in Table 5.

	Equipment	Details	Insulation Withstand Limits (Present Specification)
i	LV neutral busbar/connections in LV fuse cabinets	Between the LV earth/neutral busbar and the metal enclosure/frame	7 kV
ii	LV neutral bushing of pole-mounted transformers	Between the LV bushing and transformer tank	7 kV
iii	LV neutral connections of ground-mounted transformers	Between the LV connections and the transformer tank	7 kV
iv	Low and high voltage cable sheaths	HV and LV cables with PVC or MDPE over sheaths	7 kV
v	The electrical installation used for building services and auxiliary supplies	(e.g. heating, lighting, battery charger supplies etc.)	1.2 kV

NOTES:
i. LV fuse cabinets and wall-mounted boards in compliance with ENA TS 37-2 in accordance with SPEN specifications can be employed in ground mounted substations, including at *Extremely High EPR* sites.
ii. Pole-mounted transformers purchased before 2019 may have a lower insulation withstand value of only 3 kV and shall not be used unless it can be established that the LV rated insulation withstand voltage of the transformer meets the 7 kV requirement.
iii. Some older ground-mounted transformers may have a lower withstand value of only 3 kV. At *Extremely High EPR* sites (e.g. ground-mounted substations fed from overhead line networks), the *Design Engineer* shall confirm the LV rated insulation withstand voltage of the transformer.
iv. Can be used for general (normal) ground-mounted and pole-mounted applications without having to be installed in ducts. In some special circumstances (e.g. LV supplies to *High EPR* sites) additional ducts may be required.
v. Designed in accordance with BS 7671 and requires special consideration in substations (see section 14.2).

Table 5 – Stress Voltage Limits

13. SUBSTATION EARTHING DESIGN PROCEDURE

This section describes the procedure to be used when carrying out a design of a secondary substation *Earthing System*.

The design of the *Earthing System* for ground mounted equipment shall ensure that *Touch* and *Step Potentials* are kept within acceptable limits. The *Touch Potentials* (based on a % of *EPR* have been pre-calculated for SPEN *Standard Earthing Arrangements* (see section 15). So, provided certain conditions are met and a pre-determined '*Target Resistance*' value is employed, then this will ensure *Step* and *Touch Potentials* are kept within permissible limits.

13.1 Preliminary Design Approach

An initial assessment shall be made by following the design process set out in Figure 9 below. This will establish if a standard earthing design can be utilised. However, sites with higher fault levels, overhead line sections, small *Network Contribution* or high soil resistivity can be particularly onerous and may require an extensive and disproportionately expensive *Earthing System*. In cases where installations do not meet relevant criteria, a more detailed assessment shall be carried out by an earthing specialist. Refer to Appendix 1 of this document for the information an earthing specialist will require to complete a bespoke study.

13.1.1 *Earthing System* Design for Abnormal Running Arrangements

There may be situations where altering the running arrangements of the network will cause the *EPR* at a substation to change. This may be particularly true where a substation is fed from an underground cable network on one side of the normal split point but could be fed during abnormal running arrangements from an overhead line. In these situations, consideration shall be given to the frequency and duration of the abnormal conditions. If it is anticipated that the abnormal condition will only be in place infrequently during fault repair, it will only be necessary to consider the normal running arrangement for the earthing design. However, for circuits where abnormal conditions are planned or occur on a more regular basis, both the normal and abnormal running arrangements shall be taken into account.

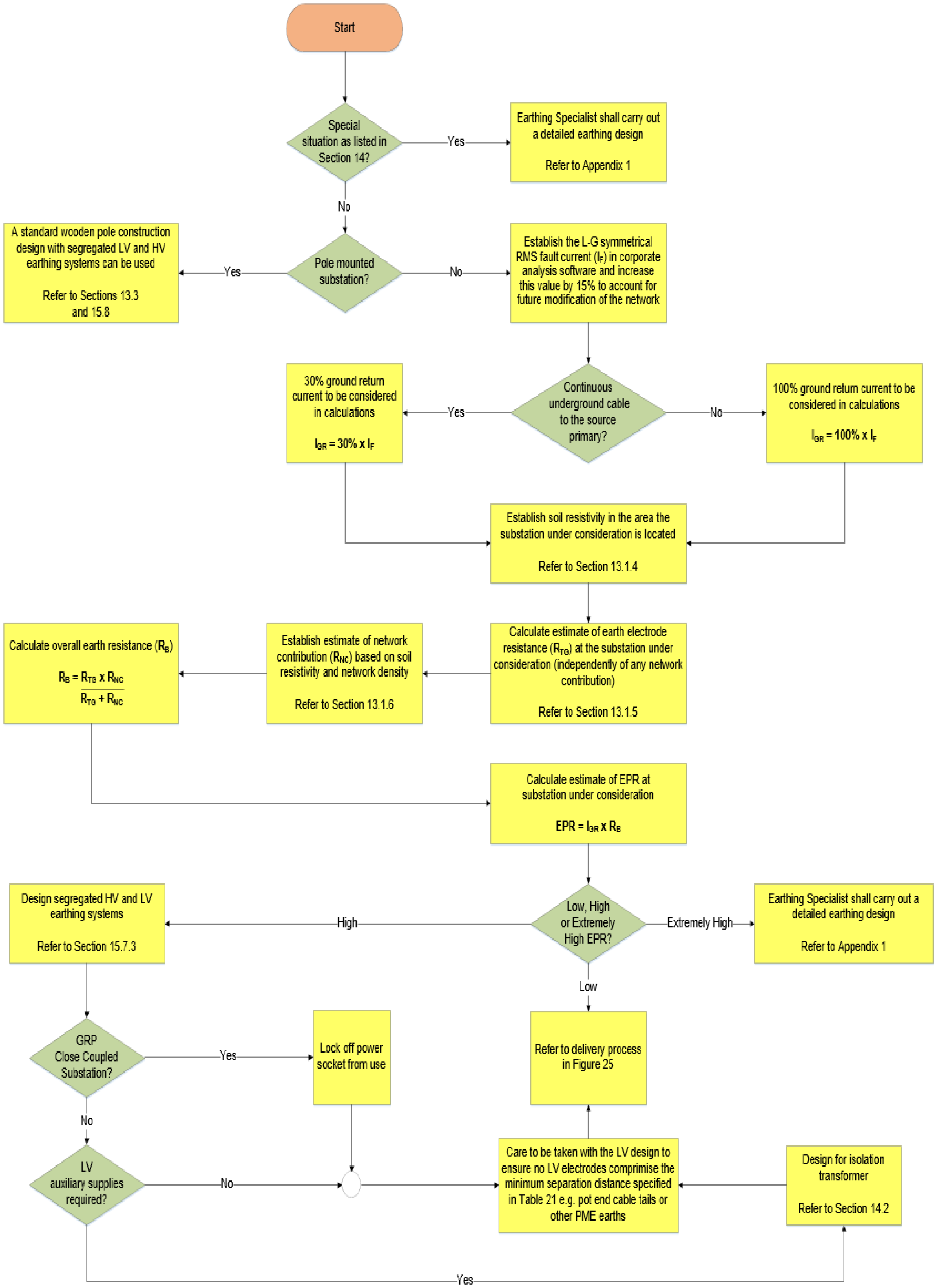


Figure 9 – Earthing Design Process

13.1.2 4 Step Approach to Design of Ground Mounted Substation Installations

Unless a new installation is one of the special situations described in section 14, it may be possible to achieve a *Low EPR* or *High EPR* (i.e. <=2.33 kV) and still achieve the safe touch and *Step Potential* limits by utilising a standard design detailed in section 15. This overall process is shown in the design flow chart (Figure 9) but can be broadly divided into the 4 main steps detailed in sections 13.1.4 to 13.1.7.

13.1.3 SPEN Distribution Substation Earthing Design Tool

The SPEN *Distribution Substation Earthing Design Tool* and supporting training videos are available for download via hyperlinks in the Substation Civils tab of the HV/LV Design Approval Guidance Template. This can be accessed via the SP Energy Networks website Information for ICPs and IDNOs - SP Energy Networks. The tool requires inputs for soil resistivity, fault current and LV earthing arrangement on the 'General Inputs' tab. The 'Local Earthing' tab helps determine the electrode design required to achieve a 10 Ω *Target Resistance* based on a selection of 4 different substation types. The '*Network Contribution*' tab facilitates determination of the *Network Contribution* using a quadrant-based approach which is illustrated in the examples contained in section 13.1.6. The 'Outputs' tab then calculates the *EPR* based on all the previous inputs and highlights the relevant *Low EPR*, *High EPR* or *Extremely High EPR* status.

The background tab allows modification of the fault clearance time, the percentage of current added for fault level headroom and the percentage of overall fault current deemed to return through the ground rather than via cable sheaths. Care should be taken to ensure the fault current does not already have 15% uplift applied before entering the value into the 'General Inputs' tab. **ICP's should not modify these settings unless agreed with the SP Energy Networks Designer responsible for their project. SP Energy Networks designers shall only modify these settings if they have sufficient knowledge and experience to make this decision and they understand the implications of these changes. Note for ICP's** – Refer to section 18 for information required in your design approval submission.

13.1.4 Step 1 – Soil Resistivity Assessment

A knowledge of soil resistivity allows the *Design Engineer* to estimate the extent of the *Earth Electrode* system required to achieve a given *Target Resistance*. This can inform decisions on whether a design is practicable / economic, or whether it is reasonable to achieve a *Low EPR* site.

The most accurate way to establish soil resistivity at a particular location is to measure it using the Wenner method as described in ENA TS 41-24. However, this is only usually carried out in difficult or problem areas, or when designing a larger (primary or grid) substation. Online data sources such as the British Geological Survey (BGS) website will provide details of soil types. This information can then be compared to the corresponding soil resistivity value in Ωm using Table 6. The BGS data may also contain borehole records in the vicinity of the proposed substation location. This can be used to provide further support to the value selected. The soil resistivity data set from BGS has been obtained under licence and can be accessed as a layer within UMV.

Typical Soil Resistivity Values (Source – ENA TS 41-24)	
Soil Type	**Resistivity (Ωm)**
Loams, garden soils etc.	5 – 50
Clays	10 – 100
Chalk	30 – 100
Clay, sand and gravel mixture	40 – 250
Marsh, peat	150 – 300
Sand	250 – 500
Slate and slatey shales	300 – 3,000
Rock	1,000 – 10,000

Table 6 – Typical Soil Resistivity Values

13.1.5 Step 2 – Local Electrode Resistance Assessment

A *Target Resistance* of 10 Ω for the HV *Earth Electrode* and 20 Ω for the LV *Earth Electrode* shall be designed for the new installation independently of any *Network Contribution* or customer *Earthing System*. To achieve a standard design as described in section 15.7.1, a perimeter electrode, 4 earth rods (one at each corner of the substation) and a steel rebar in the foundation (or grading electrode under the operators standing position) bonded to the main earth bar will be required as a minimum. Additional horizontal electrode may also be required in areas of higher soil resistivity or if the depth of rods specified in Table 7 cannot be achieved due to ground conditions. In these instances, additional analysis by an earthing specialist may be necessary to ensure high voltage contours under fault conditions do not adversely affect other low voltage *Earthing Systems*.

Local Electrode Resistances for Various Substation Types (Source SPEN Earthing Calculator)				
Soil Resistivity (Ωm)	**Substation Type**	**Earth Rod Length (m)**	**Additional Horizontal Electrode (m)**	**Overall Resistance (Ω)**
16	GRP Close Coupled Substation (4 earth rods, 3m x 3m perimeter electrode)	1.2	0	1.95
	Standard Brick 11kV Substation (4 earth rods, 4.15m x 3.69m perimeter electrode)	1.2	0	1.64
	Rectangular Double RMU/Transformer (4 earth rods, 5m x 8m perimeter electrode)	1.2	0	1.19
	Square Double RMU/Transformer (4 earth rods, 6m x 6m perimeter electrode)	1.2	0	1.27
32	GRP Close Coupled Substation (4 earth rods, 3m x 3m perimeter electrode)	1.2	0	3.90
	Standard Brick 11kV Substation (4 earth rods, 4.15m x 3.69m perimeter electrode)	1.2	0	3.27
	Rectangular Double RMU/Transformer (4 earth rods, 5m x 8m perimeter electrode)	1.2	0	2.37
	Square Double RMU/Transformer (4 earth rods, 6m x 6m perimeter electrode)	1.2	0	2.54
64	GRP Close Coupled Substation (4 earth rods, 3m x 3m perimeter electrode)	1.2	0	7.79
	Standard Brick 11kV Substation (4 earth rods, 4.15m x 3.69m perimeter electrode)	1.2	0	6.54
	Rectangular Double RMU/Transformer (4 earth rods, 5m x 8m perimeter electrode)	1.2	0	4.74
	Square Double RMU/Transformer (4 earth rods, 6m x 6m perimeter electrode)	1.2	0	5.09
125	GRP Close Coupled Substation (4 earth rods, 3m x 3m perimeter electrode)	2.4	5	8.87
	Standard Brick 11kV Substation (4 earth rods, 4.15m x 3.69m perimeter electrode)	1.2	5	8.92
	Rectangular Double RMU/Transformer (4 earth rods, 5m x 8m perimeter electrode)	1.2	0	9.27
	Square Double RMU/Transformer (4 earth rods, 6m x 6m perimeter electrode)	1.2	0	9.93
200	GRP Close Coupled Substation (4 earth rods, 3m x 3m perimeter electrode)	1.2	20	9.53
	Standard Brick 11kV Substation (4 earth rods, 4.15m x 3.69m perimeter electrode)	1.2	20	8.87
	Rectangular Double RMU/Transformer (4 earth rods, 5m x 8m perimeter electrode)	1.2	10	9.48
	Square Double RMU/Transformer (4 earth rods, 6m x 6m perimeter electrode)	1.2	10	9.90

Local Electrode Resistances for Various Substation Types (Source SPEN Earthing Calculator)				
Soil Resistivity (Ωm)	**Substation Type**	**Earth Rod Length (m)**	**Additional Horizontal Electrode (m)**	**Overall Resistance (Ω)**
300	GRP Close Coupled Substation (4 earth rods, 3m x 3m perimeter electrode)	2.4	40	9.26
	Standard Brick 11kV Substation (4 earth rods, 4.15m x 3.69m perimeter electrode)	1.2	40	9.28
	Rectangular Double RMU/Transformer (4 earth rods, 5m x 8m perimeter electrode)	1.2	30	9.51
	Square Double RMU/Transformer (4 earth rods, 6m x 6m perimeter electrode)	1.2	30	9.78

Table 7 – Local Electrode Resistances for Various Substation Types

Table 8 shows the resistance for a given horizontal *Earth Electrode* length laid in ground of various soil resistivity values.

Horizontal *Earth Electrode Resistance* (Ω) (i)								
Conductor Length	**Soil Resistivity**							
	25 Ωm	**50 Ωm**	**100 Ωm**	**150 Ωm**	**200 Ωm**	**300 Ωm**	**400 Ωm**	**500 Ωm**
10 m	3.6	7.3	14.6	21.9	29.2	43.8	58.3	72.9
25 m	1.8	3.5	7.0	10.5	14.0	21.0	28.0	35.0
50 m	1.0	2.0	3.9	5.9	7.9	11.8	15.8	19.7
100 m	0.5	1.1	2.2	3.3	4.4	6.6	8.8	11.0
150 m	0.4	0.8	1.5	2.3	3.1	4.6	6.2	7.7
200 m	0.3	0.6	1.2	1.8	2.4	3.6	4.8	6.0
250 m	0.2	0.5	1.0	1.5	2.0	3.0	4.0	5.0

Notes:
i. Conductor resistance calculated using formulae R7 from ENA EREC S34 and *Earth Electrode Resistance* calculated using formulae R4 from ENA EREC S34.

Table 8 – Horizontal *Earth Electrode* Resistance

Table 9 shows the resistance for a vertically driven earth rod of a given length for various soil resistivity values.

Total Rod Length (m)	**Resistance provided by vertically driven rod (Ω) (i)**							
	25 Ωm	**50 Ωm**	**100 Ωm**	**150 Ωm**	**200 Ωm**	**300 Ωm**	**400 Ωm**	**500 Ωm**
1.2	17.9	35.8	71.6	107.4	143.2	214.7	286.3	357.9
2.4	10.1	20.2	40.4	60.6	80.8	121.2	161.5	201.9
3.6	7.2	14.4	28.7	43.1	57.4	86.1	114.9	143.6
4.8	5.6	11.2	22.5	33.7	45.0	67.5	90.0	112.5
6.0	4.6	9.3	18.6	27.9	37.2	55.8	74.3	92.9
7.2	4.0	7.9	15.9	23.8	31.8	47.7	63.6	79.5
8.4	3.5	7.0	13.9	20.9	27.8	41.7	55.6	69.6
9.6	3.1	6.2	12.4	18.6	24.8	37.2	49.6	62.0
10.8	2.8	5.6	11.2	16.8	22.4	33.6	44.8	56.0
12	2.6	5.1	10.2	15.3	20.4	30.6	40.8	51.1

Notes
i. The earth rod resistance has been calculated using formulae R1 from ENA EREC S34.

Table 9 – Resistance Provided by Vertically Driven Rod

13.1.6 Step 3 – *Network Contribution* Assessment

Network Contribution is the term given to multiple parallel *Earth Electrodes* interconnected to a substation via metallic cable sheaths. In isolation and depending on the magnitude of the fault current, a substation electrode with a *Target Resistance* of 10 Ω could result in a relatively *High EPR*. However, when considering the parallel paths via cable sheaths to other nearby substations in a large surrounding network, the overall *Earth Electrode Resistance* can be substantially reduced.

The *Network Contribution* element is difficult to establish accurately at the design stage. It is often impractical to measure the *Network Contribution* in *Global Earthing Systems (GES)* given the presence of existing metallic conductors in the ground and the difficulty in carrying out a fall of potential measurement in areas with predominantly roads and footpaths. Therefore, unless connected to a GES, the level of *Network Contribution* provided by the local network shall be confirmed by measurement as described in section 17. However, in many cases a conservative estimate can be made to expedite the design process.

In older networks, *Network Contribution* may be provided by lead sheathed (PILC / PILC SWA) cables that are in contact with the surrounding soil such that they effectively reduce the combined earth resistance of the substation (cables with electrode effect). In new conurbations where modern installations utilise non PILC cabling, the value of applicable *Network Contribution* may also be based on the number of substations interconnected via the cable screens. Both of these contributions are only effective within a given radius, the size of which is dependent on the soil resistivity (refer to definition of effective radius in section 8).

Network must be connected via underground metallic cable sheaths to provide network contribution. If there is a section of overhead line breaking a circuit, any network beyond this point will not contribute to reducing the overall electrode resistance value.

The tables below show the maximum *Network Contribution* (i.e. that providing the lowest possible *Earth Resistance* value) that may be expected in various scenarios. The tables provide estimates for different combinations of network density for both PILC and non PILC cable types across a range of soil resistivity. The tables work on a quadrant-based approach, with each quadrant representing a portion of the existing network surrounding the new substation. Each additional quadrant provides additional contribution, therefore lowering the overall resistance value. **The tables also assume that cables of the given type extend through the quadrant all the way to the limit of the effective area. If this is not the case (e.g. cable network runs only 800 m in an effective area of 1600 m) then the resistance value will be higher than those shown in the tables.**

The parameters are conservative to necessarily err on the side of caution to ensure that the design is safe.

Soil Resistivity (Ωm)	Effective Area Radius (m)	Network Contribution Minimum Earth Resistance (Ω) One Quadrant	Network Contribution Minimum Earth Resistance (Ω) Two Quadrants	Network Contribution Minimum Earth Resistance (Ω) Three Quadrants	Network Contribution Minimum Earth Resistance (Ω) Four Quadrants
16	300	0.08	0.04	0.03	0.02
32	500	0.11	0.06	0.04	0.03
64	800	0.17	0.08	0.06	0.04
125	1100	0.24	0.12	0.08	0.06
200	1600	0.35	0.18	0.12	0.09
300	2000	0.44	0.22	0.15	0.11

Table 10 – PILC Cables – High Density & HV & LV *Network Contribution*

Soil Resistivity (Ωm)	Effective Area Radius (m)	Network Contribution Minimum Earth Resistance (Ω) One Quadrant	Network Contribution Minimum Earth Resistance (Ω) Two Quadrants	Network Contribution Minimum Earth Resistance (Ω) Three Quadrants	Network Contribution Minimum Earth Resistance (Ω) Four Quadrants
16	300	0.24	0.12	0.08	0.06
32	500	0.31	0.15	0.10	0.08
64	800	0.45	0.23	0.15	0.11
125	1100	0.66	0.33	0.22	0.16
200	1600	0.96	0.48	0.32	0.24
300	2000	1.19	0.6	0.4	0.3

Table 11 – Non PILC Cables – High Density & HV & LV *Network Contribution*

Soil Resistivity (Ωm)	Effective Area Radius (m)	Network Contribution Minimum Earth Resistance (Ω) One Quadrant	Network Contribution Minimum Earth Resistance (Ω) Two Quadrants	Network Contribution Minimum Earth Resistance (Ω) Three Quadrants	Network Contribution Minimum Earth Resistance (Ω) Four Quadrants
16	300	0.09	0.04	0.03	0.02
32	500	0.12	0.06	0.04	0.03
64	800	0.17	0.09	0.06	0.04
125	1100	0.25	0.13	0.08	0.06
200	1600	0.36	0.18	0.12	0.09
300	2000	0.45	0.23	0.15	0.11

Table 12 – PILC Cables – Medium Density & HV & LV *Network Contribution*

Soil Resistivity (Ωm)	Effective Area Radius (m)	Network Contribution Minimum Earth Resistance (Ω) One Quadrant	Network Contribution Minimum Earth Resistance (Ω) Two Quadrants	Network Contribution Minimum Earth Resistance (Ω) Three Quadrants	Network Contribution Minimum Earth Resistance (Ω) Four Quadrants
16	300	0.34	0.17	0.11	0.09
32	500	0.42	0.21	0.14	0.11
64	800	0.62	0.31	0.21	0.15
125	1100	0.89	0.45	0.30	0.22
200	1600	1.31	0.65	0.44	0.33
300	2000	1.61	0.81	0.54	0.40

Table 13 – Non PILC Cables – Medium Density & HV & LV *Network Contribution*

Soil Resistivity (Ωm)	Effective Area Radius (m)	Network Contribution Minimum Earth Resistance (Ω) One Quadrant	Network Contribution Minimum Earth Resistance (Ω) Two Quadrants	Network Contribution Minimum Earth Resistance (Ω) Three Quadrants	Network Contribution Minimum Earth Resistance (Ω) Four Quadrants
16	300	0.09	0.04	0.03	0.02
32	500	0.12	0.06	0.04	0.03
64	800	0.17	0.09	0.06	0.04
125	1100	0.25	0.12	0.08	0.06
200	1600	0.36	0.18	0.12	0.09
300	2000	0.45	0.23	0.15	0.11

Table 14 – PILC Cables – Low Density & HV & LV *Network Contribution*

Soil Resistivity (Ωm)	Effective Area Radius (m)	Network Contribution Minimum Earth Resistance (Ω) One Quadrant	Network Contribution Minimum Earth Resistance (Ω) Two Quadrants	Network Contribution Minimum Earth Resistance (Ω) Three Quadrants	Network Contribution Minimum Earth Resistance (Ω) Four Quadrants
16	300	0.76	0.38	0.25	0.19
32	500	1.26	0.63	0.42	0.31
64	800	2.50	1.25	0.83	0.62
125	1100	4.94	2.47	1.65	1.23
200	1600	9.75	4.87	3.25	2.44
300	2000	14.41	7.20	4.80	3.60

Table 15 – Non PILC Cables – Low Density & HV & LV *Network Contribution*

13.1.7 Step 4 – Calculation of *EPR*

ENA TS 41-24 provides details of the maximum *Touch Potential* a person can withstand for a given protection clearance time. For the standard design approach, a maximum HV protection clearance time of 1 second shall be used. The standard design assumes a *High EPR* of 2.33 kV will result in a *Touch Potential* of no greater than 233 V (i.e. 10% of *EPR*). This meets the requirements of permissible *Touch Potential* for someone wearing shoes on soil or outdoor concrete.

Permissible touch potentials(A) (V)	Fault clearance time (s)																			
	0.1	.15	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	2	3	5	≥10(B)
Bare feet (with contact resistance)	521	462	407	313	231	166	128	106	92	84	80	76	73	71	69	67	63	60	58	57
Shoes on soil or outdoor concrete	2070	1808	1570	1179	837	578	420	332	281	250	233	219	209	200	193	188	173	162	156	153
Shoes on 75 mm chippings	2341	2043	1773	1331	944	650	471	371	314	279	259	244	232	223	215	209	192	180	173	170
Shoes on 150 mm chippings or dry(C) concrete	2728	2379	2064	1548	1095	753	544	428	361	321	298	280	266	255	246	239	220	205	198	194
Hand-to-hand dry conditions, large contact area (see 4.3.1)	1114	968	836	639	484	368	276	221	191	172	161	152	146	141	137	134	125	119	115	114

NOTE: These values are based on fibrillation limits. Immobilisation or falls/muscular contractions could occur at lower voltages. Steady state or standing voltages may require additional consideration.

A. Additional resistances apply based on footwear resistance as well as contact patch, as defined in BS EN 50522, i.e. each shoe is 4 kΩ and the contact patch offers 3xρ, where ρ is the resistivity of the substrate in Ω·m. Thus for touch potential, the series resistance offered by both feet is 2150 Ω for shoes on soil/wet concrete (effective ρ=100 Ω·m). For 75 mm chippings, each contact patch adds 1000 Ω to each foot, giving 2500 Ω (effective ρ=333 Ω·m). For 150 mm chippings (and a conservative estimate for dry concrete), the total resistance is 3000 Ω (effective ρ = 670 Ω·m). Concrete resistivity typically will vary between 2,000-10,000 Ω·m (dry) and 30-100 Ω·m (saturated).

B. The >= 10 s column is an asymptotic value which may be applied to longer fault duration. This is a fibrillation limit only; it may be prudent to apply lower limits to longer duration faults or steady state voltages sufficient to limit body current to let-go threshold values.

C. Dry assumes indoors. Outdoor concrete, or that buried in normally wet areas or deep (>0.6 m) below ground level should be treated in the same way as soil.

Figure 10 – Permissible *Touch Potentials* vs Fault Clearance Times

Consider the simple underground cable circuit in Figure 11 below:

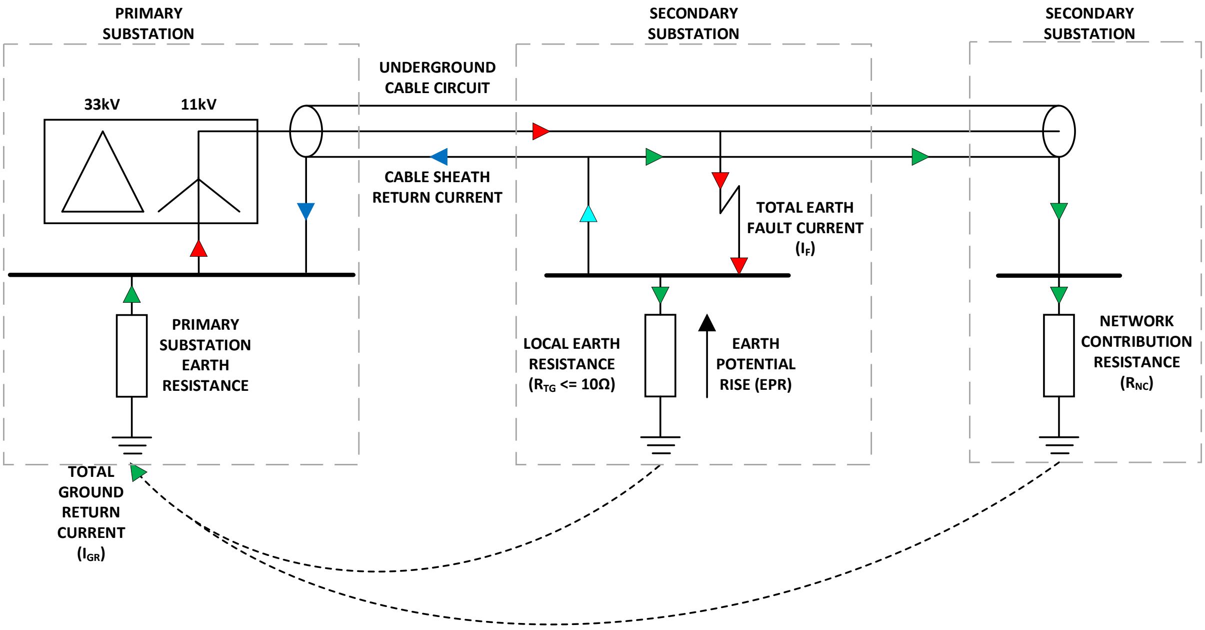


Figure 11 – Passage of Fault Current in an Underground Cable Circuit

For a high voltage *Earth Fault* in the secondary substation the rise in earth potential (*EPR*) on the *Earthing System* will be defined by:

I_{GR} = GR% x I_F
EPR = I_{GR} x R_B

I_{GR} = Ground Return Current
I_F = Total *Earth Fault Current*
R_B = Resistance of secondary substation earth electrode in parallel with any network contribution
GR% = Percentage of the total *Earth Fault Current* which returns through the general mass of earth

The percentage of the total fault current assumed to return via the metallic cable sheaths of underground cables is 70%. The remaining 30% will pass into the soil through any interconnected substation earth electrodes and any PILC/PILC SWA cable sheaths which connect them together. To make this assumption, there can be no break in the cable sheath metallic earth by an overhead line. High voltage overhead lines do not have an earth wire so if this is the case, 100% of the total fault current will flow through the soil and back to the primary substation earth electrode.

The preferred method to calculate EPR is to use the *SPEN Distribution Substation Earthing Design Tool*. However, examples of manual calculations for *Low EPR*, *High EPR* and *Extremely High EPR* are provided in Appendix 2.

13.2 Ground-mounted Substations

For ground mounted systems, the *Design Engineer* shall:

i. Apply the SPEN *Standard Earthing Arrangement* detailed in section 15.7 based on the *EPR* determined from the design flow chart in Figure 9. Ideally a scenario to achieve a *Low EPR* should be selected if conditions permit this.

ii. Select a *Target Resistance* of 10 Ω for the HV *Earth Electrode* and 20 Ω for the LV *Earth Electrode.*

13.3 Pole-mounted Installations

For pole mounted installations the *Design Engineer* shall:

i. Choose a SPEN *Standard Earthing Arrangement* from the types specified in section 15.8.

ii. Select a *Target Resistance* of 20 Ω for the HV *Earth Electrode* and 20 Ω for the LV *Earth Electrode.*

iii. Ensure the HV *Earth Electrode* is installed (as far as reasonably practicable) away from often frequented livestock areas.

14. SPECIAL SITUATIONS REQUIRING ADDITIONAL PRECAUTIONS

14.1 Secondary Substations in High Risk Areas

The *Touch Potential* and *Step Potential* limits given in section 12.1.4 and 12.1.5 are applicable for the vast majority of substation sites. However, the following sensitive locations require special consideration:

i. Close to areas where people may be expected to be barefoot (gardens, outdoor play areas) and/or at wet locations such as swimming pools, paddling pools, showers, schools/nurseries etc.

ii. Within 20 m of a fuel filling station, e.g. to supply forecourt electric vehicle chargers.

iii. Close to concentrations of livestock (e.g. stables, milking parlours, pens etc.)

Higher risk situations can occur when LV and HV *Earthing Systems* are combined in ground mounted substations fed by overhead lines. This risk is further elevated when such substations supply the sensitive locations outlined above. The combination of high or *Extremely High EPR* and higher risk factors for people with wet feet, combustion of flammable fuel or livestock can present a significant danger which should be addressed. At such sites special precautions may be justified to eliminate or minimise the risk. Such precautions may involve careful site selection, positioning of the HV *Earth Electrode* in a direction away from the area of concern or burying the electrode as deep as practicable.

Where possible, secondary substations shall not be installed near to such high-risk areas. If this is unavoidable, then a detailed design assessment shall be undertaken by an *Earthing Specialist* to optimise the location of the substation *Earth Electrode* to control the risk.

14.2 Provision of Building Services / Auxiliary Supplies to *High EPR* Sites

High EPR sites are required to be operated with segregated HV/LV *Earthing Systems* (i.e. HV/LV Link shall be left opened). Where building service or auxiliary supplies (e.g. for substation heating, lighting, RTU or battery charger supplies) are installed at *High EPR* sites, then additional precautions are required to avoid the *High EPR* being exported onto the LV network and to avoid Operators coming into contact between different *Earthing Systems*.

This includes situations where an external (i.e. remotely earthed) LV supply is brought into the substation from the LV network or where the LV supply is taken directly from the local LV cabinet or fuse-board. The insulation withstand of the equipment (i.e. *Stress Voltage*) shall be verified to ensure that that breakdown between LV phase/neutral/earth to HV steelwork earth cannot occur internally.

Light switches, power sockets and conduits etc shall preferably be plastic. Alternatively, metallic light switches, conduits and sockets shall be bonded to the HV Earthing system. Additionally, the following precautions should be taken based on the type of equipment utilised.

Equipment With Integrated Power Socket

On LV cabinets fitted with a 13 A socket, the LV isolator switch on the LV cabinet/LV fuse board controlling the 13 A socket shall be opened and padlocked at all *High EPR* sites. Some older LV cabinets/fuse boards may not be fitted with an isolator switch, and in this case, the 13 A sockets shall be disconnected. If the *Design Engineer* can establish by calculation that the *EPR* will not exceed the relevant *Low EPR* limit and the *Stress Voltage* of the 13 A socket will not be exceeded (see section 12.1.6) then the isolator switch can be left closed and socket can remain connected.

Equipment With Separate LV Supplies (e.g. Battery Charger, Sockets, Conduits and Light Switches)

An isolation transformer shall be installed between the LV system and the substation building service/auxiliary supply installation unless the *Design Engineer* can establish by calculation that the *EPR* will not exceed the relevant *Low EPR* limit. A diagram of the isolation transformer installation is shown in Figure 12. SWG-03-026 provides details on isolation transformers and ratings to be used at substations for providing building service and auxiliary supplies. Table 16 provides guidance on rating of isolation transformer (where required) depending on *EPR* Level.

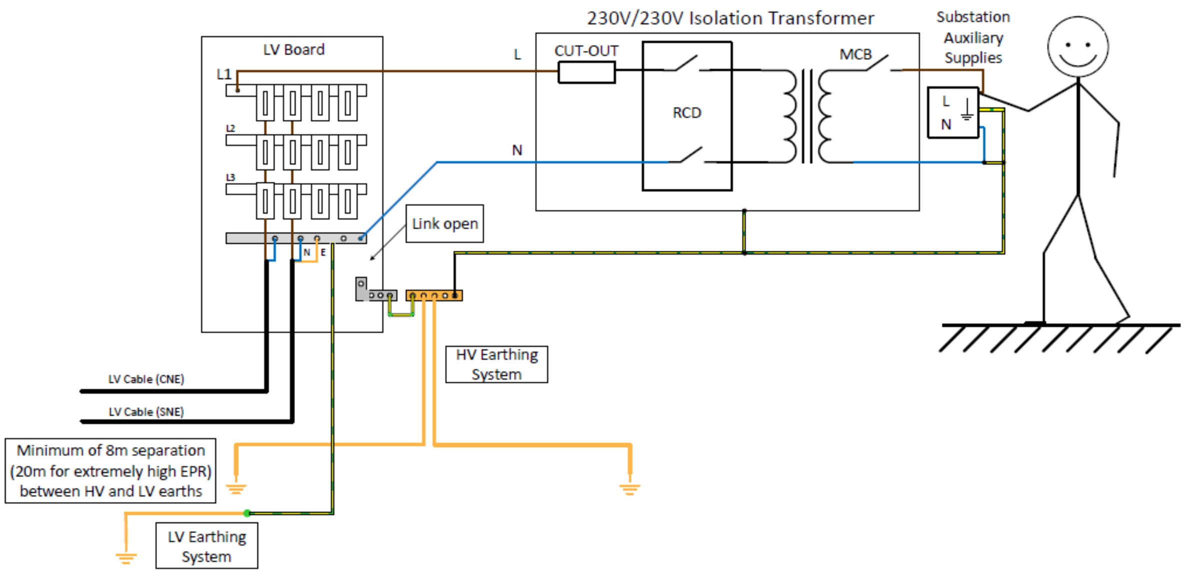


Figure 12 – Isolation Transformer Installation

EPR level	Combined/ Segregated Earthing	Isolation transformer	Isolator Switch Position	Comments
Low EPR	Combined	Not required	Closed	See section 12.1.1
High EPR	Segregated	4 kV Rated Insulation Level (*Stress Voltage*)	Open	Limited by transformer neutral insulation. See section 12.1.3 and 12.1.6
Extremely High EPR	Segregated	7 kV Rated Insulation Level (*Stress Voltage)*	Open	See section 12.1.3

Table 16 – Limits for Installation of Isolation Transformer

14.3 Secondary Substations Located Within a Grid or Primary Substation

Where dedicated secondary substations are installed inside grid or primary substations this may utilise one of the *Standard Earthing Arrangements* given in section 15. Two connections shall be made between the secondary substation *Main Earth Bar* and grid or primary substation *Main Earth Bar*. The secondary substation HV and LV *Earthing Systems* shall be combined. This is acceptable for *High EPR* sites where the secondary substation only feeds the primary substation auxiliary supply.

Secondary substations inside grid/primary substations shall not be used to supply customers.

14.4 Secondary Substations Near Railways

Secondary substations located near to, or providing supplies to, railway infrastructure (especially AC or DC electrified systems) shall be referred to an *Earthing Specialist* who will assess the additional risks. The *Design Engineer* shall liaise with both the *Earthing Specialist* and the railway infrastructure owner as necessary to ensure that the *Earthing System* employed at the site is appropriate.

14.5 Secondary Substations Near Conductive Pipelines

Where practicable, secondary substations (and their *Earth Electrodes*) should not be installed within 50 m of a conductive pipeline. Where this is unavoidable, the pipeline operator shall be approached to obtain construction details and operator requirements. An *Earthing Specialist* shall also be consulted to assess the impact of the substation on the pipeline under steady state and fault conditions. The assessment required will depend on the type of pipeline and the corrosion mitigation measures employed (e.g. cathodic protection).

14.6 Lightning Protection Systems

Lightning protection design is covered in BS EN 62305-1. If a lightning protection system is connected to the substation *Earthing System* at a *High EPR* site, it is possible that dangerous potentials can be exported around the site under HV fault conditions.

Building or site lightning protection systems may be connected to the secondary substation HV *Earthing System* providing that:

i. The lightning protection system has an independent earth resistance of 10 Ω or lower (before connection to the SPEN *Earthing System*);
ii. The substation is a *Low EPR* site.

If the above statements are not satisfied guidance shall be sought from an *Earthing Specialist*.

15. STANDARD EARTHING ARRANGEMENTS

This section provides detailed arrangements and layouts for *Standard Earthing Arrangements* that shall be employed in SPEN.

The *Standard Earthing Arrangements* have been developed to cover a range of typical ground-mounted substations and pole-mounted installations used in SPEN. There will be some situations where standard arrangements are not suitable, and it is the responsibility of the *Design Engineer* to exercise a degree of judgement, and to seek help from an *Earthing Specialist* if there is any doubt that the use of the *Standard Earthing Arrangement* is not appropriate at that site.

For ground mounted substations, SPEN's *Standard Earthing Arrangement* is designed to achieve a *Touch Potential* of 10% or less of *EPR.* Therefore, if *EPR* is limited to 2.33 kV (see section 12.1.2), the *Touch Potential* will not exceed 233 V. *Standard Earthing Arrangements* are not defined for *Extremely High EPR* sites, i.e. *EPR* greater than 2.33 kV. For *Extremely High EPR* sites, a specialist earthing study will be required in all cases.

For pole-mounted transformers, the HV metalwork is placed out of reach to ensure that staff and public are not exposed to hazardous *Touch Potentials. Standard Earthing Arrangements* ensure sufficient separation of the LV and HV earth electrode systems to avoid potentially dangerous voltages being transferred to a customer's LV earthing terminal.

If it is particularly difficult to achieve the *Target Resistance* at a site due to particularly onerous ground conditions or installation is not practicable, the designer shall seek advice from an *Earthing Specialist.*

15.1 Conductor Size and Type – Ground-mounted Substation

The conductor size and type for each element of a ground mounted substation earthing installation is detailed in Table 17 below. Refer to sections 15.3-15.6 for further details.

The minimum size of HV *Earthing Conductors* used in all ground-mounted secondary substations is based on being able to carry the *Earth Fault Current (Design)* level of 13.1 kA for a duration of 3 seconds.

Voltage	Installation Type – Ground Mounted Substation	Above or Below Ground?	Conductor Size & Type
HV	HV Main *Earth* Bar	Above	25 mm x 6 mm Bare Copper Tape or 50 mm x 4 mm Bare Aluminium Tape (bare Copper not to be used above ground in locations where there is a high risk of metal theft)
	HV Equipment Equipotential Bonding	Above	120 mm^2 PVC Covered Stranded Copper
	Ancillary Equipment Equipotential Bonding	Above	16 mm^2 PVC Covered Stranded Copper
	HV Perimeter **Loop** Electrode	Below	70 mm^2 Bare Stranded Copper
	Additional Horizontal Electrode	Below	120 mm^2 Bare Stranded Copper
	HV Rods (minimum of 1 at each corner of the perimeter electrode)	Below	Copper Clad Steel Rods – Shank Diameter 14.2 mm (Nominal Diameter 16 mm)
LV	LV Transformer Star Point Bonding	Above	70 mm^2 PVC Covered Stranded Copper
	LV Buried Electrode	Below	70 mm^2 Bare Stranded Copper (use 70 mm^2 PVC Covered Stranded Copper if HV/LV segregation is required)
	LV Rods	Below	Same specification as HV rods

Table 17 – Conductor Sizes and Types for Ground-mounted Substations

15.2 Conductor Size and Type – Pole-mounted Substation

The conductor size and type for each element of a pole mounted substation earthing installation is detailed in Table 18 below. Refer to sections 15.3-15.6 for further details.

The minimum size of HV *Earthing Conductors* used at pole-mounted secondary installations is based on the HV System *Earth Fault Current (Design)* level applicable to the site (see section 11.1). A level of 4 kA for a duration of 3 seconds can be employed for the vast majority of pole-mounted sites in SPEN. 70 mm^2 copper will carry 7.4 kA as a single connection and 12.4 kA when duplicated. This is based on a temperature rise of 250°C above 30°C ambient.

Installation Type – Pole Mounted Substation	Conductor Size & Type
HV Electrode on Pole	70 mm^2 PVC Covered Stranded Copper
HV Buried Electrode	70 mm^2 Bare Stranded Copper
HV Rods	Copper Clad Steel Rods – Shank Diameter 14.2 mm (Nominal Diameter 16 mm)

Table 18 – HV Conductor Sizes and Types for Pole-mounted Substations

The size of LV *Earthing Conductors* that shall be used is given in Table 19.

Installation Type – Pole Mounted Substation	Conductor Size & Type
LV Electrode on Pole	70 mm^2 PVC Covered Stranded Copper
LV Buried Electrode to Achieve Segregation from HV Buried Electrode	70 mm^2 PVC Covered Stranded Copper
LV Buried Electrode	70 mm^2 Bare Stranded Copper
LV Rods	Same specification as HV rods

Table 19 – LV Conductor Sizes and Types for Pole-mounted Substations

The size of *Earthing Conductors* detailed allow for a maximum temperature rise of 250°C and are appropriate for bolted connections. These are based on *Backup Protection* operation. All main items of plant that may be subjected to HV *Earth Fault Current* (e.g. transformers, HV switchgear, HV metering units, HV cable screens/sheaths etc.) shall be connected to the substation *Main Earth Bar* using suitably rated *Earthing Conductors*. This may be achieved by using a fully rated single conductor or duplicate conductors.

15.3 LV Earthing Conductors

The LV *Earth Electrode* shall be connected to the neutral bar in the LV fuse-cabinet/pillar/board or neutral terminal of a pole-mounted transformer using a PVC insulated stranded copper conductor.

15.4 Bonding Conductors

Any exposed normally un-energised metalwork within a substation which may become live can present a safety hazard to personnel.

All current carrying items of equipment including HV switchgear, LV fuse-cabinet/pillar/board and LV ACB shall have an earth terminal connected to the *Main Earth Bar* using an independent connection.

All other ancillary equipment (e.g. control units, RTUs, battery chargers etc.) shall be earthed to the appropriate *Earth Terminal* using a minimum of 16 mm^2 insulated copper earthing conductor (or equivalent). The purpose of such bonds is to form an equipotential zone, i.e. to eliminate hand-to-hand voltages, but not to carry significant current.

Small extraneous parts not likely to attain any rise in potential (e.g. small window frames, handrails etc.) need not be bonded at secondary substations.

15.5 Buried Earth Electrodes

For all installations, bare *Earth Electrodes* shall be buried at least 0.6 m below ground level to provide an effective electrical connection with the general mass of earth shall have sufficient surface area to carry the current into soil.

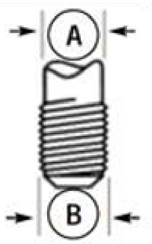
On underground *Earth Electrodes*, bolted connections shall not be used.

HV *Earth Electrodes* have sufficient thermal rating to be able to carry fault currents up to the value of HV *Earth Fault Current (Design)* for that system.

The HV *Earth Electrodes* used at ground-mounted substations shall have a sufficient thermal capacity to be able to withstand the HV System *Earth Fault Current (Design)* level of 13.1 kA for 3 s. This may be achieved by using a fully rated single conductor. Alternatively, duplicate conductors can be used where specified (e.g. where a ring of perimeter *Earth Electrode*s are buried around the substation as shown in Figure 13 and Figure 15) and the size of single conductor can then be reduced accordingly. In ground-mounted substations, a ring of bare copper is laid around the substation to form the perimeter loop *Earth Electrode*. Thus, if 70 mm^2 is employed then this provides an equivalent *Earth Electrode* cross section of 140 mm^2.

15.6 Earth Rods

As a minimum, HV Rods should be installed 1 at each corner of the perimeter electrode. The rods generally come in sections of 1.2 m and can be screwed together to make longer rods as required. Rods should be of copper clad steel construction with a nominal diameter (B) of 16 mm and shank diameter (A) 14.2 mm in accordance with ENA TS 43-94.



Shank Diameter – A (mm)	Nominal Diameter – B (mm)	Nominal Length (m)
14.2	16	1.2

Table 20 – Earth Rod Dimensions

15.7 Ground-Mounted Substations

15.7.1 Overview

The *Earthing System* arrangement for ground-mounted substations is based on a buried *Earth Electrode* system which includes a ring of bare copper conductor (“perimeter electrode”) encapsulating all exposed metalwork to provide an area of lower *Touch Potentials* within the substation. The perimeter electrode shall be installed at a depth of 600 mm or greater to ensure it remains in stable (wet/damp) soil. In the event that a perimeter electrode cannot be installed and the site is not *Low EPR*, a detailed earthing study is required.

The perimeter ring is supplemented by four earth rods located at each corner, primarily to reduce earth resistance. These rods may be driven deeper to reduce the substation resistance. Where it is not practical to drive one or more of the rods then the Design shall include lengths of horizontally laid electrode, e.g. installed in cable trenches, to replace the effect of the rods and to achieve the *Target Resistance*. Where it is not practical to install rods or horizontal electrodes a detailed earthing study is required.

The steel rebar in the concrete foundation slab shall also be bonded to the main earth bar. However, in cases where the operator would not stand inside the structure to undertake switching activity, it is not necessary to bond the foundation rebar in the plinth to the main earth bar. In such instances, e.g. a close coupled GRP substation, an *Earth Electrode* shall be installed under the operator position instead. This ensures that the HV switchgear can only be operated while standing above the *Earth Electrode*.

This grading electrode or “Earth mat” shall be buried no greater than a maximum depth of 300 mm in accordance with ENA TS-41-24.

In the *Standard Earthing Arrangements*, where the substation enclosure is non-metallic, the perimeter electrode may be installed closely around the edge of the foundation. Special situations, where the substation enclosure is metallic, (e.g. pad mount substations) are not covered by the *Standard Earthing Arrangement* and in these situations, a detailed earthing study is required.

Internal connections shall connect from the perimeter *Earth Electrode* to all items of plant via the *Main Earth Bar*. These internal connections function as an *Earthing Conductor* if not in contact with soil, or an *Earth Electrode* otherwise.

Touch Potentials may be further reduced by connection of horizontal reinforcing bars in the foundation and by an additional loop of horizontal *Earth Electrode* in front of the substation in the areas where doors open, and an operator is most likely to be present.

The main parameters that can be varied by the *Design Engineer* are the length of earth rods, and the extent of any additional *Earth Electrodes* (if any) installed outside the footprint of the substation. No other variations of the *Standard Earthing* Arrangements are permitted.

All SPEN standard ground-mounted designs achieve a *Touch Potential* of 10% or less of *EPR*. The maximum *EPR* for these must in any case not exceed 2.33 kV, but will usually be limited to lower values dependent on floor/ground covering.

For substations which are not *Low EPR*, there may exist a *Touch Potential* hazard if the metalwork (or anything connected to it) can be touched from outside the substation. The highest risk will most likely be to members of public. In these situations, care shall be taken in selecting a substation location and avoiding placement of HV electrodes in the vicinity of other LV earthing systems. Metallic fences may also present a risk (see section 16.5). Where possible, all equipment shall be housed within a GRP enclosure to completely eliminate this risk to the public. The risk to operators with access inside the substation will be managed by the design of the *Earthing System*.

Where the LV and HV *Earthing Systems* require to be segregated then separation between the HV and LV *Earthing Systems* shall be provided by installing an insulated LV *Earthing Conductor* between the substation and LV *Earth Electrode system.*

At High EPR, sites a minimum separation distance in soil shall be provided between the HV and LV Earthing Systems as defined in Table 21 below. It is important to consider separation distance of the HV earthing system from both the LV earthing electrodes associated with the new substation installation and any other existing LV earthing electrodes in the vicinity, particularly LV PILC cables. The separation must also be observed from any LV earth connected metalwork, e.g. lampposts and other street furniture. If the separation distances cannot be achieved in practice, then a full earthing design shall be carried out by an Earthing Specialist to determine if a smaller separation distance can be achieved.

Table 21 provides segregation distances for each standard earthing arrangement substation type. The distances vary depending on the type of LV earthing system employed. Care should be taken to consider all LV earthing system types in the vicinity (e.g. a PME housing site could be the new installation, with existing PILC LV cables in close proximity to the new substation HV electrode).

When considering the segregation of the new HV and LV earthing systems, the route and insulated length of LV earthing conductor are important. However, achieving sufficient separation between the new HV earthing electrode and any existing LV earthing electrodes may prove more difficult to manage. The location of the new substation is of paramount importance and should be considered at design stage. Additional horizontal HV earth electrodes may also transfer high EPR to existing LV electrodes some distance away from the substation, so the route of these electrodes must be designed to maintain the minimum required separation distance along its entire length. Consideration should also be given to any future development where the HV electrode may subsequently be in proximity to LV earth electrodes.

At *Extremely High EPR* sites, minimum separation will be confirmed by an *Earthing Specialist* design.

The insulated LV *Earthing Conductor* shall be kept separate from HV cables and HV *Earth Electrodes* In line with normal practice, it is usual to route the LV *Earthing Conductor* in the same trench as outgoing LV cables.

Substation Arrangement	Minimum Separation Distance of HV/LV for Cable Fed Substation	
	PME (TN-C-S) Public LV Network	**SNE (TN-S) Private LV Network**
GRP Close Coupled Substation (4 earth rods, 3m x 3m perimeter electrode)	8 m	12 m
Standard Brick 11 kV Substation (4 earth rods, 4.15m x 3.69m perimeter electrode)	10 m	15 m
Rectangular Double RMU/Transformer (4 earth rods, 5m x 8m perimeter electrode)	15 m	23 m
Square Double RMU/Transformer (4 earth rods, 6m x 6m perimeter electrode)	15 m	23 m

Table 21 – Minimum Separation Distance Between HV and LV *Earthing Systems* for Standard Secondary Substation Earthing Arrangements (For mixed PME/SNE networks, use SNE values)

When installing cable tails with pot ends on spare fuse ways of LV boards, the tails should be of sufficient length to ensure that the *Earth Electrode* in the pot end is not at risk of transfer potential from the HV *Earthing System*.

The *Standard Earthing Arrangements* for ground-mounted substations are based on the following design criteria:

i. *Touch Potentials and Step Potentials* shall be below permissible limits (refer to sections 12.1.4 and 12.1.5).

ii. The *EPR* shall be limited as defined in section 12.1.1 where reasonably practicable. Sites which satisfy this requirement are defined as having a *Low EPR.* In which case, the HV and LV *Earthing Systems* are combined. It is permitted to install an HV *Earthing System* only in this case (see Figure 13). **The HV/LV Earthing link inside the LV cabinet shall be closed**.

iii. Where the *EPR* cannot be limited to *Low EPR*, then reasonable steps shall be taken to limit the *EPR* to 2.33 kV (see section 12.1.2). These sites are considered to be *High EPR* sites and the HV and LV *Earthing Systems* shall be segregated in soil by at least the distance specified in Table 21 for the appropriate substation arrangement. **The HV/LV Earthing link inside the LV cabinet shall be opened**.

iv. In some exceptional situations (e.g. ground-mounted substations fed from overhead lines with no *Network Contribution*), it may not be practicable to limit the *EPR* to 2.33 kV (see section 12.1.3). These sites are considered to be *Extremely High EPR* sites. In these cases, the HV and LV *Earthing Systems* shall be separated in soil by a distance specified by an *Earthing Specialist* design. **The HV/LV Earthing link inside the LV cabinet shall be opened**. A special substation design shall be chosen capable of operating with an *EPR* up to 6.35 kV.

v. The HV *Earth Electrode Resistance* shall not exceed 10 Ω. This value is necessary to provide reliable and fast protection operation during *Earth Faults*.

vi. The LV *Earth Electrode Resistance* shall not exceed 20 Ω in accordance with EART-01-002.

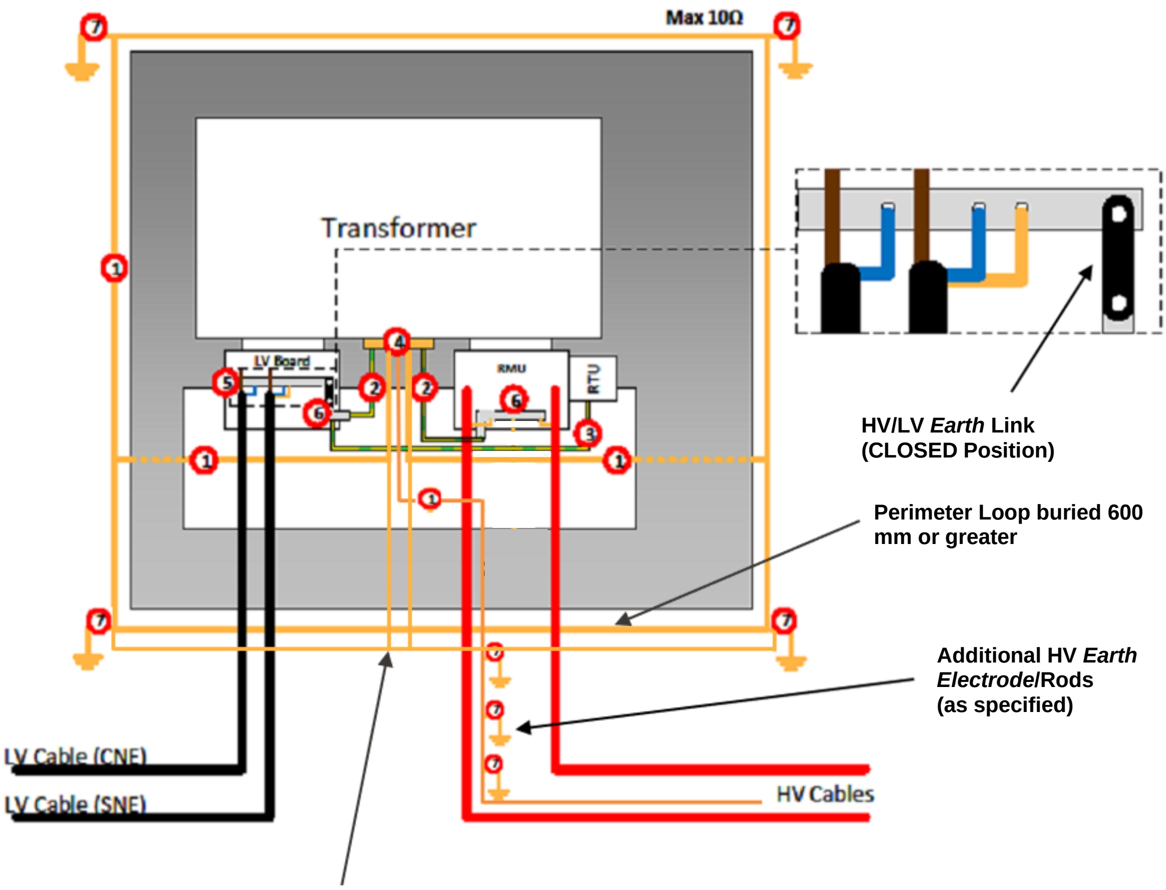
vii. *Earthing Conductors* and *Earth Electrodes* shall be of sufficient size to safely carry the maximum *Fault Current (Design)* of 13.1 kA for 3 s. (See sections 11.1 and 15.1).

15.7.2 GRP with Combined HV and LV *Earthing Systems*

The *Standard Earthing Arrangement* for GRP substations with combined HV and LV *Earthing Systems* (i.e. *Low EPR* site) is shown in Figure 13 and Figure 14. This is the usual and preferred arrangement for urban areas (e.g. *GES* locations) where *EPR* is low.

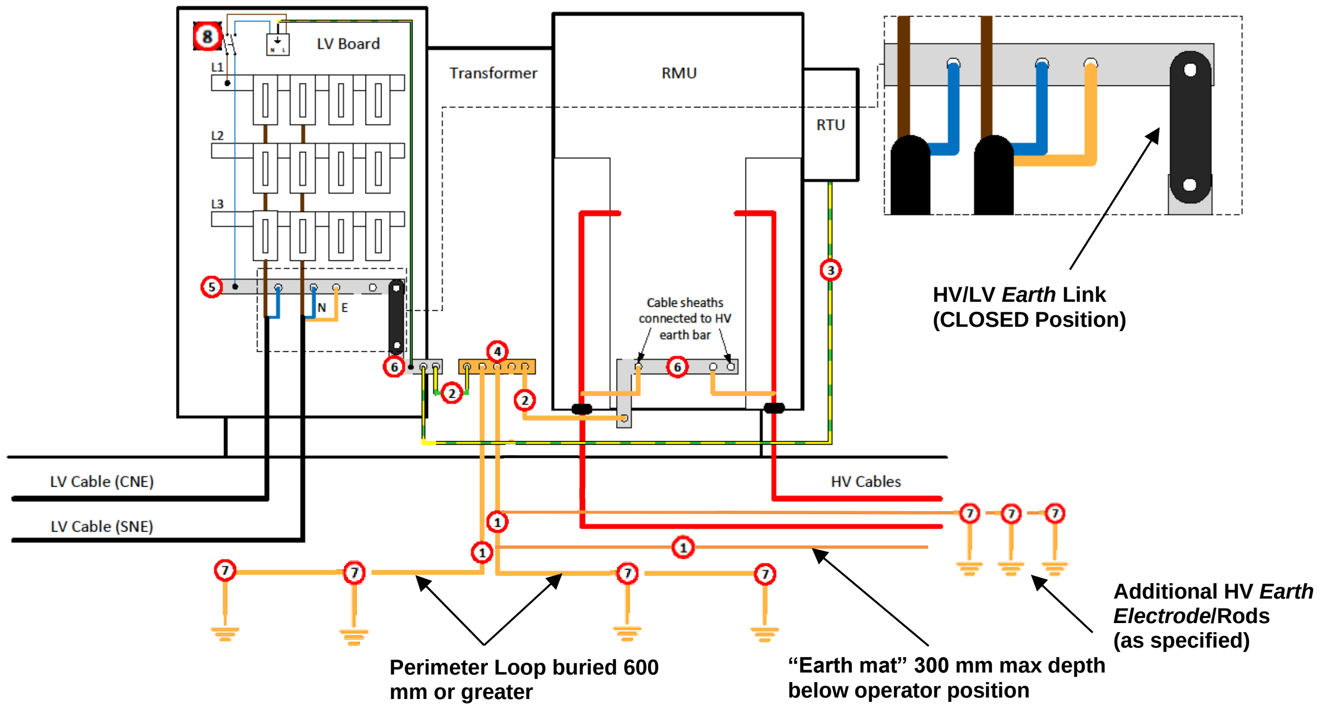
In *GES* locations, it is permissible to install an HV *Earthing System* and HV *Earth* Electrode system only.

The HV/LV Earthing link inside the LV cabinet shall be CLOSED.



1	70 mm^2 Bare HV *Earth Electrode.* (Installed around the perimeter of substation and immediately in front of HV switchgear at operator position)
2	120 mm^2 PVC Insulated *Earthing Conductor*. (Used to connect all plant to *Main Earth Bar)*
3	16 mm^2 PVC Insulated *Bonding Conductor*. Used to bond ancillary equipment (e.g. RTU) to Main *Earth* Bar
4	Transformer Tank HV *Main Earth Bar.*
5	LV Neutral /LV *Earth* terminal inside LV fuse cabinet.
6	HV *Earth terminal* inside LV fuse cabinet/On RMU. (**HV/LV Link CLOSED)**
7	HV earth rods. As many as required to achieve 10 Ω resistance. (Positioned at each corner as standard and if required along the HV cable pit)

Figure 13 – Earthing Arrangement for GRP Substation in a GES – Combined HV and LV Earths



1	70 mm^2 Bare HV *Earth Electrode.* (Installed around the perimeter of substation and immediately in front of HV switchgear at operator position)
2	120 mm^2 PVC Insulated *Earthing Conductor*. Used to connect all plant to Main *Earth* Bar.
3	16 mm^2 PVC Insulated *Bonding Conductor*. (Used to bond ancillary equipment (e.g. RTU) to *Main Earth Bar)*
4	Transformer Tank HV *Main Earth Bar.*
5	LV Neutral /LV *Earth* terminal inside LV fuse cabinet.
6	HV *Earth terminal* inside LV fuse cabinet/On RMU. (**HV/LV Link CLOSED)**
7	HV earth rods. As many as required to achieve 10 Ω resistance. (Positioned at each corner as standard and if required along the HV cable pit)
8	13 A Socket Isolator Switch. **This can be left closed** (*EPR* will be less than *Low EPR*). See section 12.1.6

Figure 14 – Earthing Arrangement for GRP Substation in a GES – Combined HV and LV Earths (Front Elevation View)

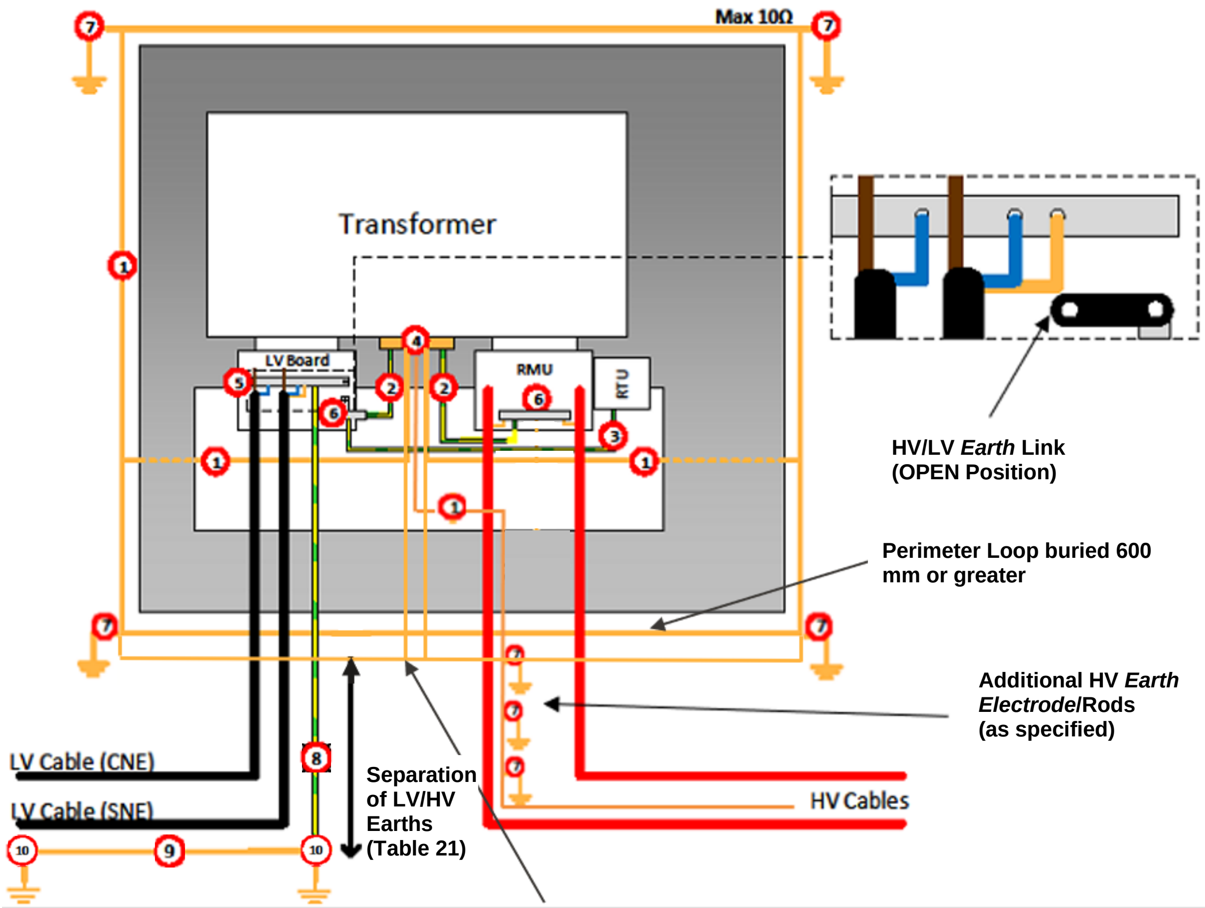
15.7.3 GRP Substation with Segregated HV and LV Earthing Systems

The *Standard Earthing Arrangement* for GRP substations with segregated HV and LV *Earthing Systems* (i.e. *High EPR* site) is shown in Figure 15 and Figure 16. This arrangement shall be employed where it is not possible to achieve a *Low EPR*.

A separate LV *Earth Electrode* system segregated from the HV *Earth Electrode* system by the distance specified in Table 21 (in soil) for the appropriate substation arrangement, shall be installed using an insulated cable and connected to the LV neutral bar inside the LV cabinet.

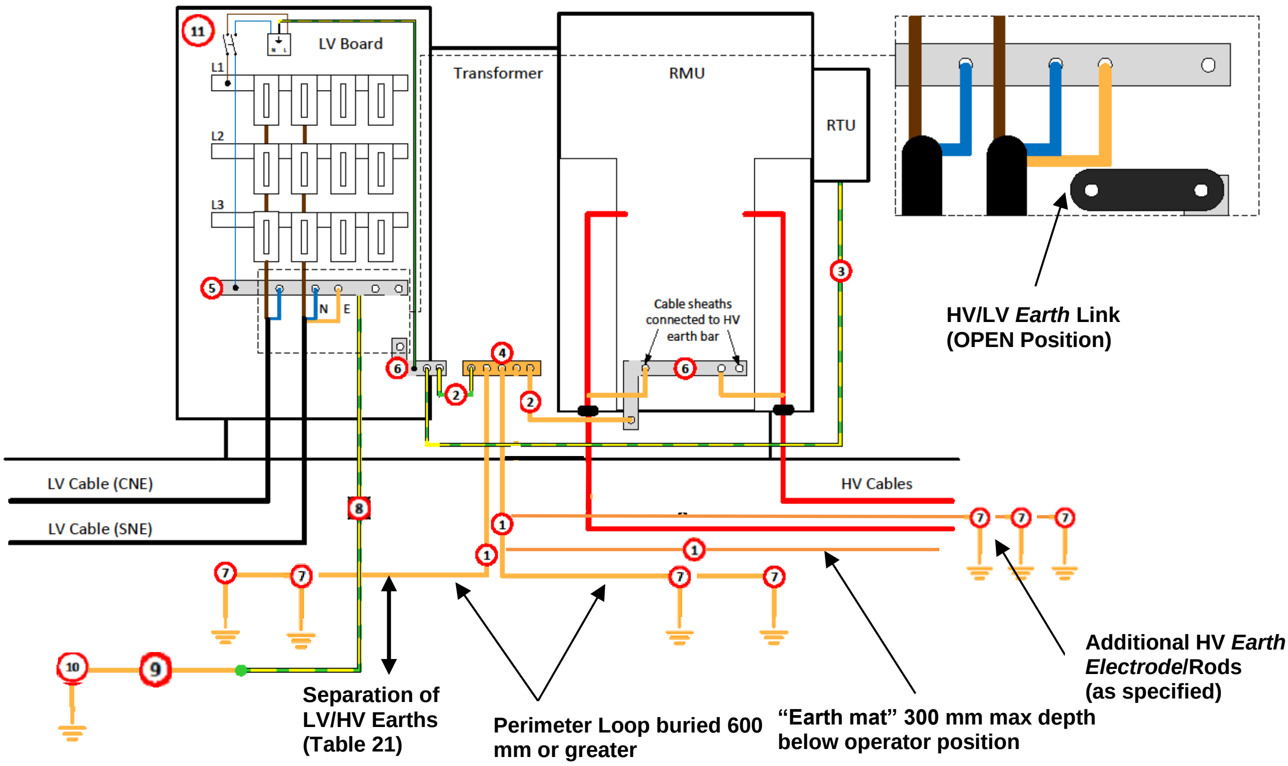
Outside of *GES*, confirmation of the design *EPR* is required by measurement on site. Even if the *EPR* is established to be low at the design stage, a segregated HV and LV *Earthing System* shall be installed. A decision may then be made on completion of testing to combine the HV/LV *Earthing Systems* if *Low EPR* can be achieved.

For *High EPR* sites, the HV/LV Earthing link inside the LV cabinet shall be OPENED.



1	70 mm^2 Bare HV *Earth Electrode.* (Installed around the perimeter of substation and immediately in front of HV switchgear at operator position)
2	120 mm^2 PVC Insulated *Earthing Conductor*. (Used to connect all plant to Main *Earth* Bar)
3	16 mm^2 PVC Insulated *Bonding Conductor*. (Used to bond ancillary equipment (e.g. RTU) to Main *Earth* Bar)
4	Transformer Tank HV *Main Earth Bar.*
5	LV Neutral /LV *Earth* terminal inside LV fuse cabinet.
6	HV *Earth terminal* inside LV fuse cabinet/On RMU. (**HV/LV Link OPEN)**
7	HV earth rods. As many as required to achieve 10 Ω resistance. (Positioned at each corner as standard and if required along the HV cable pit)
8	70 mm^2 PVC Insulated LV *Earthing Conductor*. (Shall provide a separation to HV *Earthing Electrode* system in accordance with the distance specified in Table 21)
9	70 mm^2 Bare LV *Earth Electrode.*
10	LV earth rod.

Figure 15 – Earthing Arrangement for GRP Substation – Segregated HV and LV Earths



1	70 mm² Bare HV *Earth Electrode.* (Installed around the perimeter of substation and immediately in front of HV switchgear at operator position)
2	120 mm² PVC Insulated *Earthing Conductor*. (Used to connect all plant to *Main Earth Bar*)
3	16 mm² PVC Insulated *Bonding Conductor*. Used to bond ancillary equipment (e.g. RTU) to *Main Earth Bar*
4	Transformer Tank HV *Main Earth Bar.*
5	LV Neutral /LV *Earth* terminal inside LV fuse cabinet.
6	HV *Earth terminal* inside LV fuse cabinet/On RMU. **(HV/LV Link OPEN)**
7	HV earth rods. As many as required to achieve 10 Ω resistance. (Positioned at each corner as standard and if required along the HV cable pit)
8	70 mm² PVC Insulated LV *Earthing Conductor.* (Shall provide a separation to HV *Earthing Electrode* system in accordance with the distance specified in Table 21)
9	70 mm² Bare LV *Earth Electrode*.
10	LV earth rod.
11	13 A Socket Isolator Switch. This shall be **Opened and Locked** if *EPR* Exceeds *Low EPR* (see section 12.1.6)

Figure 16 – Earthing Arrangement for GRP Substation – Segregated HV and LV Earths (Front Elevation View)

15.7.4 Ground-Mounted Substation for Sites with an *Extremely High EPR*

The *Standard Earthing Arrangements* are not applicable at *Extremely High EPR* sites and the *Design Engineer* shall consult an *Earthing Specialist* to ensure that the design of the *Earthing System* is appropriate to control *Touch* and S*tep Potentials* within permissible limits. Soil resistivity measurements will be required to determine the most effective *Earthing System* design.

15.7.5 Customer HV Supplies and Associated Substations

SPEN is not responsible for network assets beyond its ownership but has a duty of care to ensure that the customer's system will not become hazardous to SPEN staff under fault conditions. The SPEN and customer *Earthing Systems* are often physically close to each other and the effect of one on the other cannot be overlooked. Interconnection of the two *Earthing Systems* is the preferred option unless the alternative can be justified (i.e. it has been demonstrated as the safest option).

The SPEN and Customer HV *Earthing Systems* shall be designed to meet the fundamental requirements for an *Earthing System* as described in section 11.1 of this specification and shall satisfy the requirements of ENA TS 41-24. These requirements shall be met independently of each other. The *Earthing Systems*, their components and *Bonding Conductors* shall be capable of distributing and discharging the fault current without exceeding thermal and mechanical design limits based on *Backup Protection* operating time.

If this is satisfied, then the two *Earthing Systems* shall be connected together via two designated connections that are duly labelled. Note that, if the combined *Earthing System* results in a *High EPR* then the associated precautions shall be applied to both the SPEN and Customer sites. (e.g. segregation of LV Earth/Neutral *Earthing System* at the customer substation, precautions to control *Transfer Potentials* onto other metallic services, etc.).

Where it is not practicable to achieve the safety requirements for *Touch Potential* and *Step Potential* limits via the SPEN *Earthing System* alone, a specialist earthing study shall be undertaken. If it is established by a specialist study that the substation may rely on the Customer's *Earthing System* to satisfy safety requirements, this is only permissible under the following conditions:

- The substation feeds a single customer only.
- A connection agreement is signed by the customer and contains a clause which requires them to maintain the earth resistance established at the commissioning stage for the duration of the connection.
- The customer *Earthing System* must be constructed to a similar standard to SPEN requirements.

The SPEN project manager shall discuss the expected EPR with the customer or their specialist and agree on whether it is appropriate to combine the SPEN HV and customer's LV earthing systems together.

15.7.6 Earthing Arrangement for HV Substations Integral to Another Building

In these circumstances it is unlikely to be practical to install a permitter earth loop around the substation and therefore not possible to fully comply with the *Standard Earthing Arrangements.* Where the EPR of the site can be assessed without doubt to be *Low EPR,* it is permissible to install earth electrodes on one side of the substation only provided the Target Resistance can be achieved. For all other cases, a detailed earthing design shall be carried out by an *Earthing Specialist*.

15.7.7 Earthing for LV only Substations

Some substations may be equipped with an LV board and no transformer or HV switchgear. For new LV only substations, an HV earthing assessment shall be carried out to determine the *EPR* classification in the same way an HV equipped substation would be assessed. For low or *High EPR* situations,

segregated HV and LV earthing systems shall be installed in accordance with the requirements set out in this specification. For *Extremely High EPR* situations, UMV shall be annotated to confirm that an HV earthing system has not been installed. If the substation is ever equipped at HV, a revised earthing assessment shall be carried out to validate that the existing earthing system is fit for purpose.

15.7.8 Securing Land Rights for Horizontal Earthing Electrodes

In some cases, extended horizontal electrodes may be specially designed to ensure safe *Touch Potential* and *Step Potential within* **ground mounted substations**. These electrodes may subsequently be at risk from third party damage and future development activities. They may also present a danger of *Transfer Potential* to any future LV supplies in that vicinity. In the case of ground mounted substations, an easement or servitude must be obtained prior to energisation of the asset.

For overhead line HV earthing systems, *Touch Potentials* are controlled by design and are in locations where the probability of future development and third party damage is much lower. However, care should be taken at design and delivery stage to ensure the landowners are aware of the potential risks to livestock. Earthing electrode routes should be designed in accordance with the requirements set out in section 14.

15.7.9 IDNO HV Supplies and Associated Substations

In the case of IDNO/SPEN shared secondary substations, the IDNO takes overall control and ownership of the HV and LV earthing systems (see section 5.5 of ENA EREC G88). The IDNO shall demonstrate that the substation *Earthing System* is designed such that in both normal and abnormal conditions there is no danger to persons. The IDNO shall confirm that the *Earthing System* is designed and installed to avoid damage to equipment due to excessive potential rise and potential differences within the earthing system (*Stress Voltage*), and due to excessive currents flowing in auxiliary paths not intended for carrying *Earth Fault* Current. All earthing designs shall comply with the requirements of ENA TS 41-24. The main requirements are to satisfy *Touch Potential* limits, and NOT export dangerous potentials onto the LV network.

The ICP will agree with the IDNO on whether it is appropriate to combine the HV and LV earthing systems together.

15.7.10 Asset Replacement

For high risk sites (section 14), additional advice shall be sought from an *Earthing Specialist*.

15.8 Pole-mounted Installations

15.8.1 Overview

The guidance in this section is based on the use of wood poles. Earthing of overhead equipment using metallic poles, masts or towers is not covered by this specification and will require an assessment by an *Earthing Specialist*. At pole-mounted installations, it is not practicable to achieve *Low EPR* levels (see section 12.1.1). Therefore, all HV steelwork shall be sited out of reach. Additionally, HV *Earthing Conductors* shall be insulated and provided with mechanical protection for a minimum height of 3 m or above the height of the anti-climbing device (whichever is greater). The *Earthing Conductors* shall also be insulated for a minimum of 1 m below ground level to avoid damage from ploughing etc.

It is also a standard requirement that HV and LV *Earthing Systems* shall be segregated at all pole-mounted substations. These precautions ensure that *Touch Potential* is less of an issue, therefore the *HV Earthing System* serves three main purposes:

i. To ensure the *HV* protection operates rapidly in the event of an *Earth Fault.*

ii. To prevent *EPR* reaching levels where flashover (to LV system) can occur.

iii. To provide some protection to transformer windings during lightning events.

The HV *Earth Electrode Resistance* (i.e. resistance from HV steelwork to the general mass of earth) shall not exceed 20 Ω. Additionally, where surge arresters are installed, the HV *Earth Electrode Resistance* shall not exceed 10 Ω (see section 16.7). SPEN's 11 kV network is directly earthed, therefore a 20 Ω *Earth Electrode* system will allow sufficient *Earth Fault* current to flow back to the primary substation to ensure the HV protection operates quickly enough. A 20 Ω earth resistance also limits the likelihood of back flashover during lightning surges and resultant transformer winding failure.

The HV *Earth Electrode* shall be installed at least 1 m below ground level to ensure as far as reasonably practicable that *Step Potentials* directly above the *Earth Electrode* system remain below permissible limits under *Earth Fault* conditions. The HV *Earth Electrode* may consist of bare horizontal *Earth Electrodes* (i.e. bare copper conductor) laid in a trench, vertical earth rods or a combination of the two. Sufficient *Earth Electrodes* shall be installed to achieve the required earth resistance. The horizontal *Earth Electrodes* will be more effective where there is an underlying high resistivity material such as rock. Vertical driven earth rods will be more effective where there is lower resistivity material beneath the surface, e.g. wetter material below the water table.

All support steelwork and the transformer tank shall be connected using PVC insulated HV *Earthing Conductors* sized in accordance with section 15.2. The PVC insulated HV *Earthing Conductor* shall be installed down the pole and connected to an HV *Earth Electrode*.

All pole-mounted transformers currently being purchased by SPEN have a rated insulation withstand voltage capability between the LV bushing and transformer tank of 7 kV in accordance with recent SPEN specifications. This ensures that in the event of an HV fault, the resultant *EPR* will not be sufficient to cause a flashover to the LV system (see section 12.1.6 covering *Stress Voltage* limits).

Note: Some older pole-mounted transformers may have a lower insulation withstand value of only 3 kV (see section 12.1.6 covering *Stress Voltage* limits). Pole-mounted transformers purchased before 2019 may have a lower insulation withstand value of only 3 kV and shall not be used unless it can be established that the LV rated insulation withstand voltage of the transformer meets the 7 kV requirement.

LV *Earth Electrodes* shall have a maximum resistance of 20 Ω in accordance with EART-01-002.

The LV *Earth Electrode* shall be installed a minimum of 20 m from the HV *Earth Electrode* either by installing the *LV Earth Electrode* at the first pole away from the pole-mounted transformer (see Figure 18) or by using an insulated conductor between the pole and the LV *Earth Electrode* system (see Figure 19). This increased separation distance compared to ground-mounted substation reflects the possible occurrence of a very high *EPR* being imposed on the pole-mounted steelwork and HV *Earth Electrodes* as a result of an *Earth Fault*. Traditional practice in SPEN has been to provide an 8 m separation, but a separation distance of 20 m is now employed based on computer modelling to demonstrate that acceptable limits for LV transfer are not exceeded for typical soil resistivity conditions. Figure 17 includes an example of how to establish the 20 m separation between the LV *Earth Electrode* and the HV *Earth Electrode*.

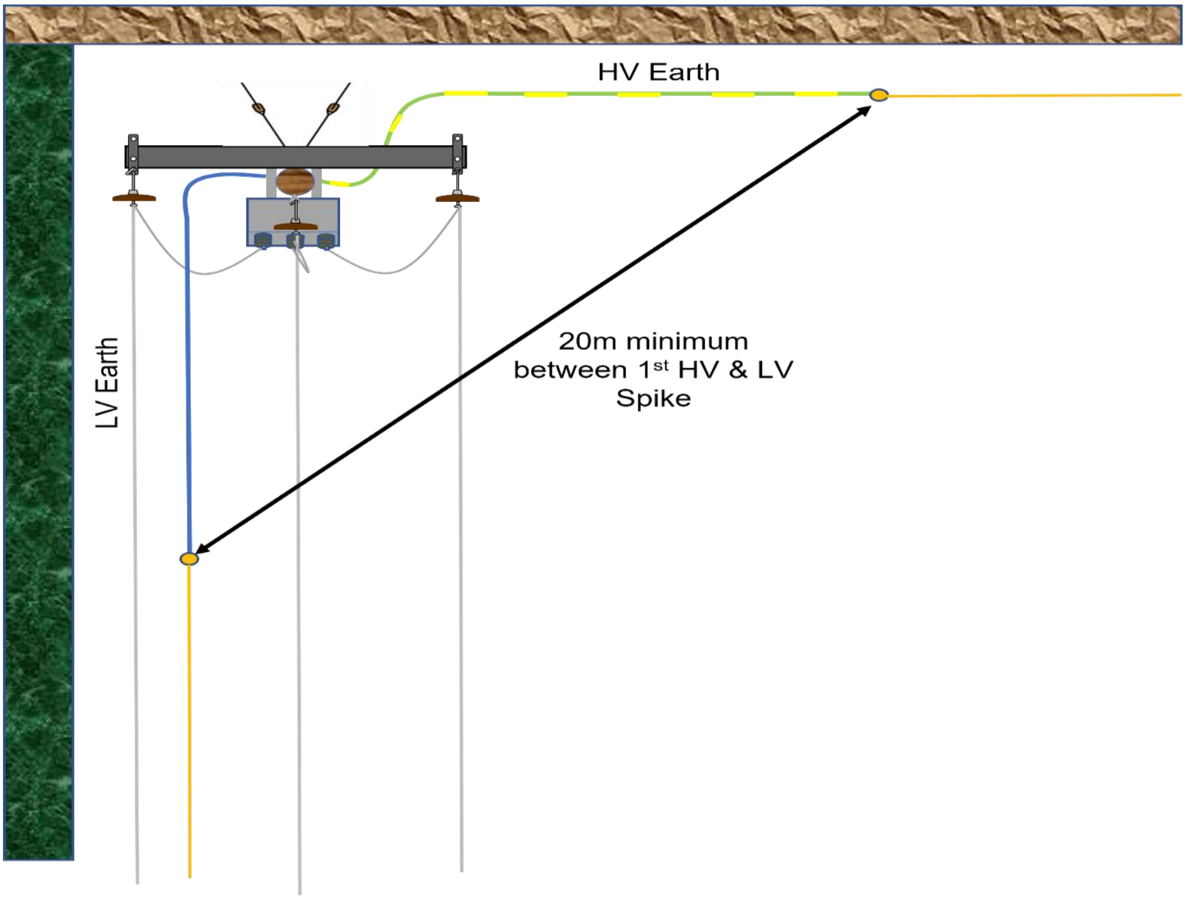


Figure 17 – Pole-mounted Transformer HV/LV Earthing Separation

If PILC type LV cables are installed on the pole, these usually cannot be isolated from earth and so it is necessary to ensure that the HV *Earth Electrode* is sited more than 20 m from the pole and insulated within this distance.

Consideration shall be given the effect of *Step Potentials* on horses and other livestock. Where practicable the HV *Earth Electrodes* shall be located away from areas of high animal usage (e.g. water troughs, milking parlours etc.). Where this is not possible a more detailed assessment of *Step Potentials* and/or risk assessment is required by an *Earthing Specialist*.

The *Standard Earthing Arrangements* for pole-mounted installations are based on the following design criteria:

i. All pole-mounted substations shall be designed with separate HV and LV *Earthing Systems* and shall be separated by at least 20 m.

ii. The HV *Earth Electrode* earth resistance shall not exceed 20 Ω in order to provide reliable protection operation. (Where surge arresters are installed, the HV *Earth Electrode* earth resistance shall not exceed 10 Ω).

iii. The LV *Earth Electrode* earth resistance shall not exceed 20 Ω to comply with EART-01-002.

iv. The HV *Earth Electrode* and *Earthing Conductors* shall be of sufficient size and surface area to safely carry fault current at that site (see sections 15.2, 15.3 and 15.5).

v. *EPR* on pole-mounted steelwork can approach system phase-to-earth voltage, which in some situations might be close to 6.33 kV. All LV equipment shall be suitably insulated and separated from HV equipment to prevent flashover during HV fault conditions.

15.8.2 Pole-mounted Transformer with LV Overhead Line

The *Standard Earthing Arrangement* for a pole-mounted transformer with LV overhead line is shown in Figure 18.

The HV *Earth Electrode* and HV *Earthing Conductor* shall be installed as described in section 15.8.1.

The separation between the buried HV and LV *Earth Electrodes* is effectively achieved by locating the LV *Earth Electrode* at the base of the first LV pole positioned greater than 20 m away from the transformer pole. The LV *Earth Electrode* shall be connected to the overhead line neutral conductor using an insulated *Earthing Conductor* with minimum cross section of 70 mm^2.

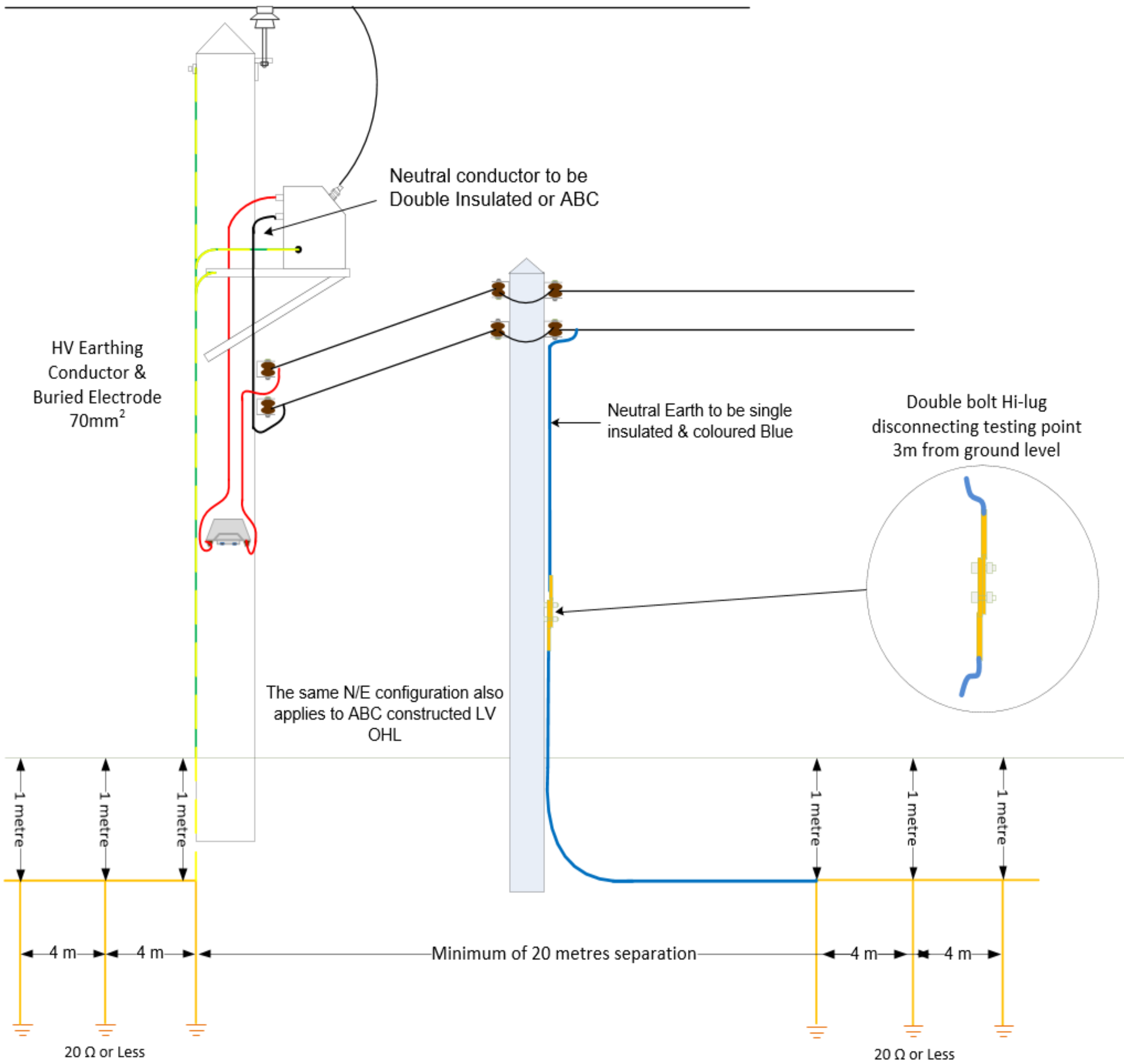


Figure 18 – Pole-mounted Transformer with LV Overhead Line

15.8.3 Pole-mounted Transformer with LV Cable

The *Standard Earthing Arrangement* for a pole-mounted transformer with LV cable is shown in Figure 19. The HV *Earth Electrode* and HV *Earthing Conductor* shall be installed as described in section 15.8.1.

The LV neutral terminal of the transformer shall be connected to earth using an insulated LV *Earthing Conductor* installed on the opposite side of the pole to the HV *Earthing Conductor*. (Where an H-pole is used the HV and LV *Earthing Conductors* shall be installed on different poles). The insulated LV *Earthing Conductor* shall be extended underground for a minimum of 20 m, separated from the HV *Earth Electrode* and connected to an LV *Earth Electrode* of bare copper with a maximum earth resistance of 20 Ω.

The LV *Earth Electrode* system may be installed in the same trench as the LV cable and, in a similar way to the HV *Earth Electrode,* a combination of horizontal and vertical electrodes may be used to provide the required earth resistance of 20 Ω.

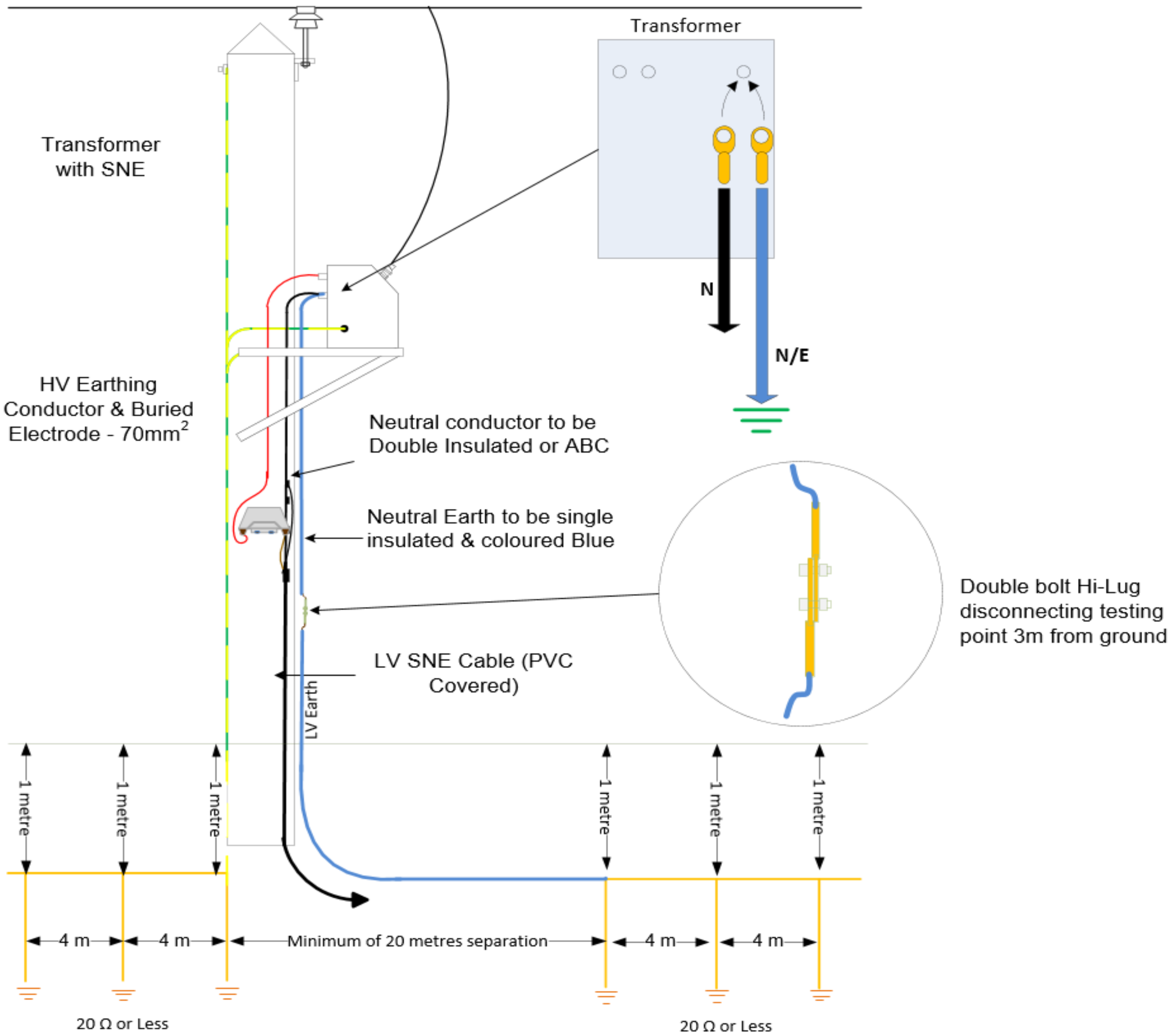


Figure 19 – Pole-mounted Transformer with LV Cable

15.8.4 HV Cable Termination (with Surge Arresters)

The *Standard Earthing Arrangement* for an HV cable termination with surge arresters is shown in Figure 20.

The HV *Earth Electrode* and HV *Earthing Conductor* shall be installed as described in section 15.8.1. The HV *Earth Electrode* and *Earthing Conductor* shall have a minimum cross-section of 70 mm^2.

To ensure the effectiveness of the surge arresters, the HV *Earthing Conductor* shall be installed as straight as possible down the pole avoiding sharp bends to an *HV Earth Electrode* with maximum earth resistance of 10 Ω in accordance with section 16.7.

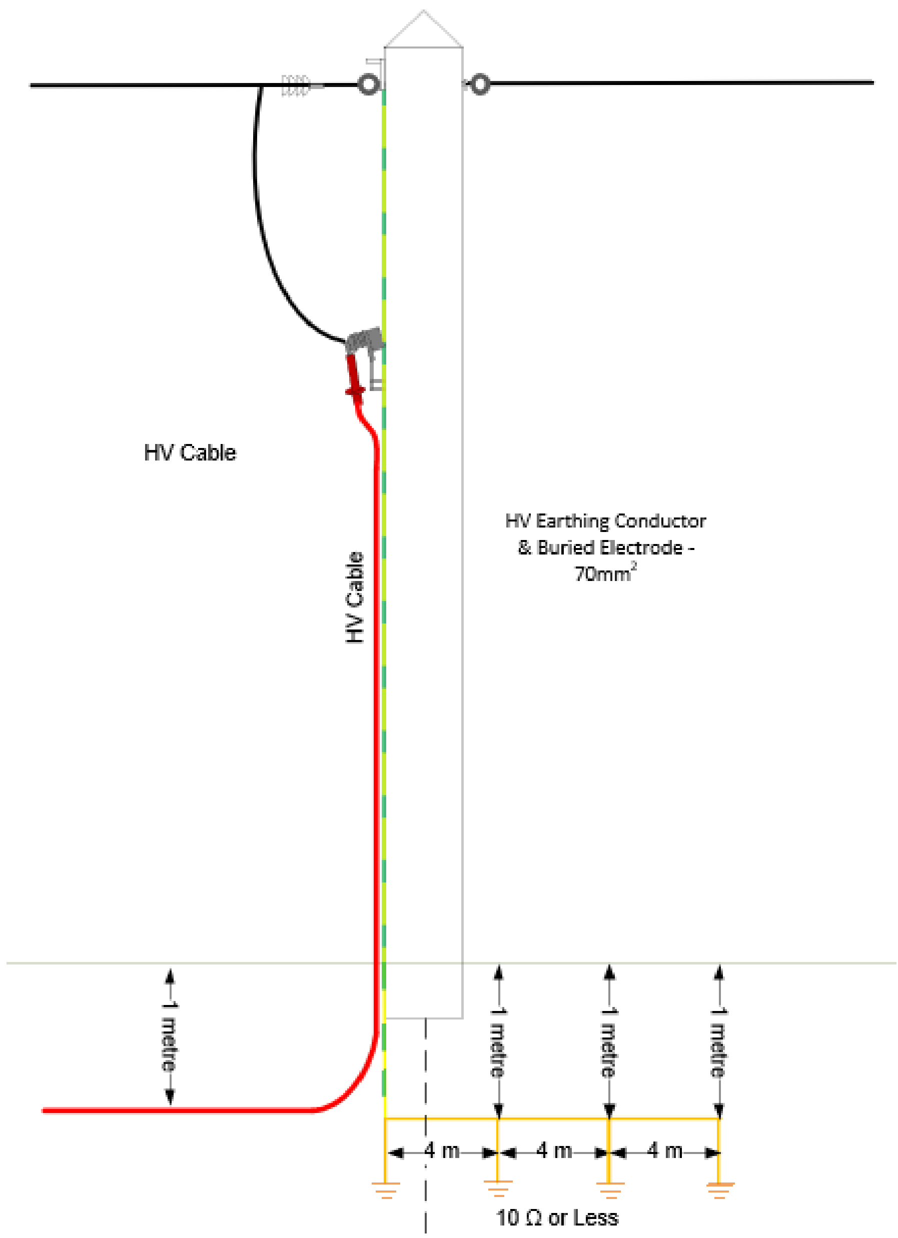


Figure 20 – HV Cable Termination with Surge Arresters

15.8.5 HV Cable Termination with Surge Arresters and HV Fuse Unit

The *Standard Earthing Arrangement* for an HV cable termination with surge arresters and HV fuse unit is shown in Figure 21.

The HV *Earth Electrode* and HV *Earthing Conductor* shall be installed as described in section 15.8.1 and shall have a maximum earth resistance of 10 Ω in accordance with section 16.7. The HV *Earthing Conductor* and *Earth Electrode* shall have a minimum cross-section of 70 mm².

In accordance with section 16.9, the *HV Earth Electrode* shall be installed at least 5 m away from the pole at a location where the Operator will not be standing when carrying out any live HV switching operations.

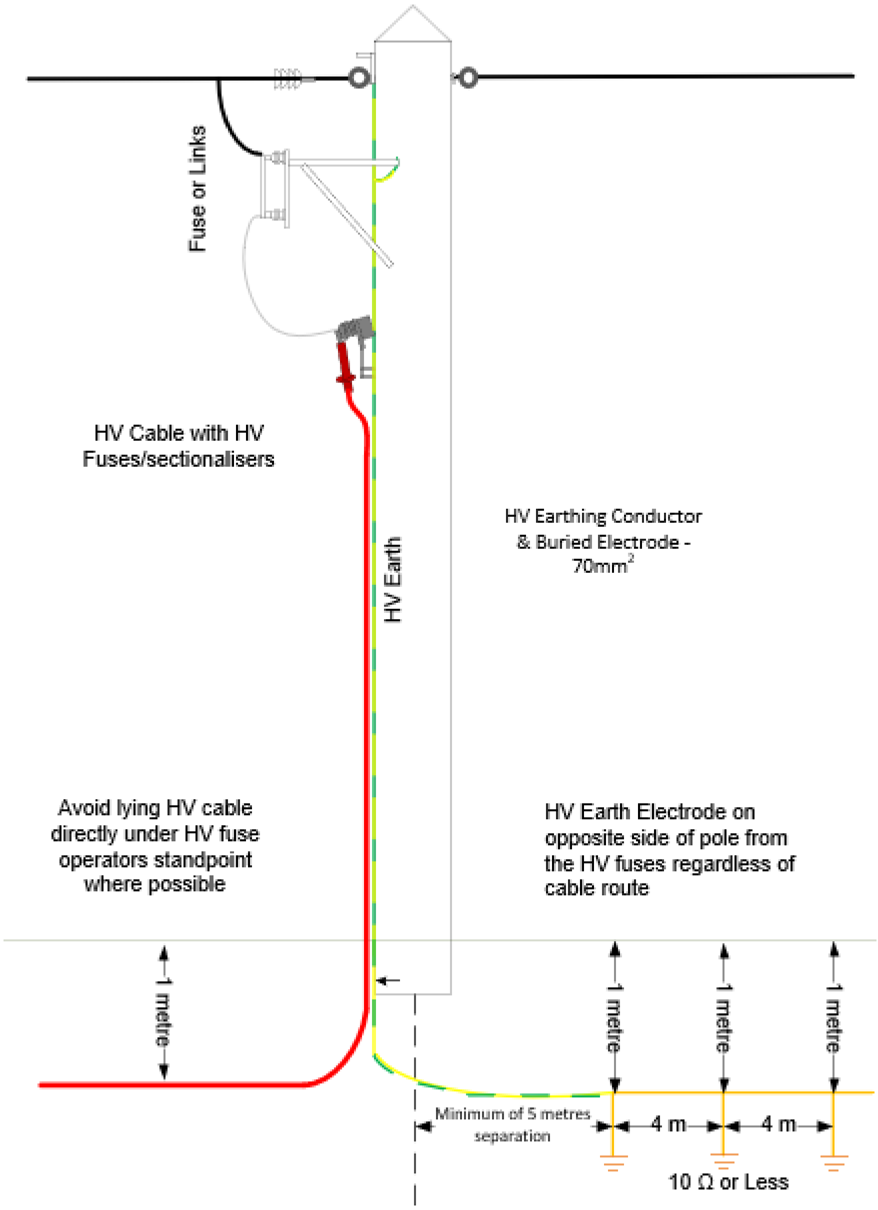


Figure 21 – HV Cable Termination with Surge Arresters and HV Fuse Unit

15.8.6 Metal Enclosed Pole-Mounted Load Break Switch Disconnector (PMSW)

The *Standard Earthing Arrangement* for a PMSW (with surge arresters) is shown in Figure 22.

The HV *Earth Electrode* and HV *Earthing Conductor* shall be installed as described in section 15.8.1 and shall have a maximum earth resistance of 10 Ω in accordance with section 16.7. The HV *Earthing Conductor* and *Earth Electrode* shall have a minimum cross-section of 70 mm^2.

In accordance with section 16.9, the *HV Earth Electrode* shall be installed at least 5 m away from the pole at a location where the Operator will not be standing when carrying out any live HV switching operations.

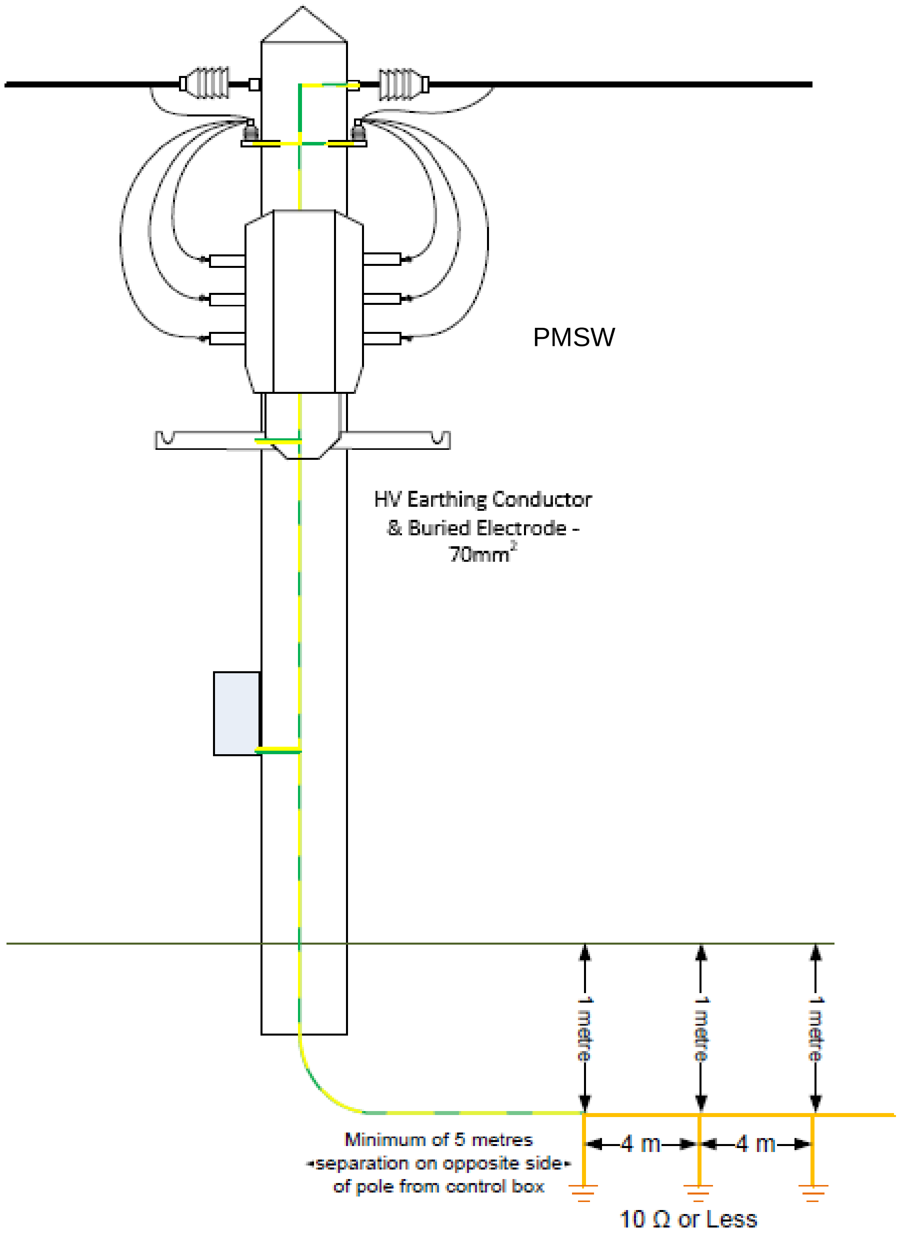


Figure 22 – Metal Enclosed Pole-mounted Load Break Switch Disconnector (PMSW)

15.8.7 Pole-mounted Auto-Recloser (PMAR) with High-level Control Unit

The *Standard Earthing Arrangement* for a PMAR with high-level control unit is shown in Figure 23.

The HV *Earth Electrode* and HV *Earthing Conductor* shall be installed as described in section 15.8.1 and shall have a maximum earth resistance of 10 Ω in accordance with section 16.7. The HV *Earthing Conductor* and *Earth Electrode* shall have a minimum cross-section of 70 mm^2.

In accordance with section 16.9, the *HV Earth Electrode* shall be installed at least 5 m away from the pole at a location where the Operator will not be standing when carrying out any live HV switching operations.

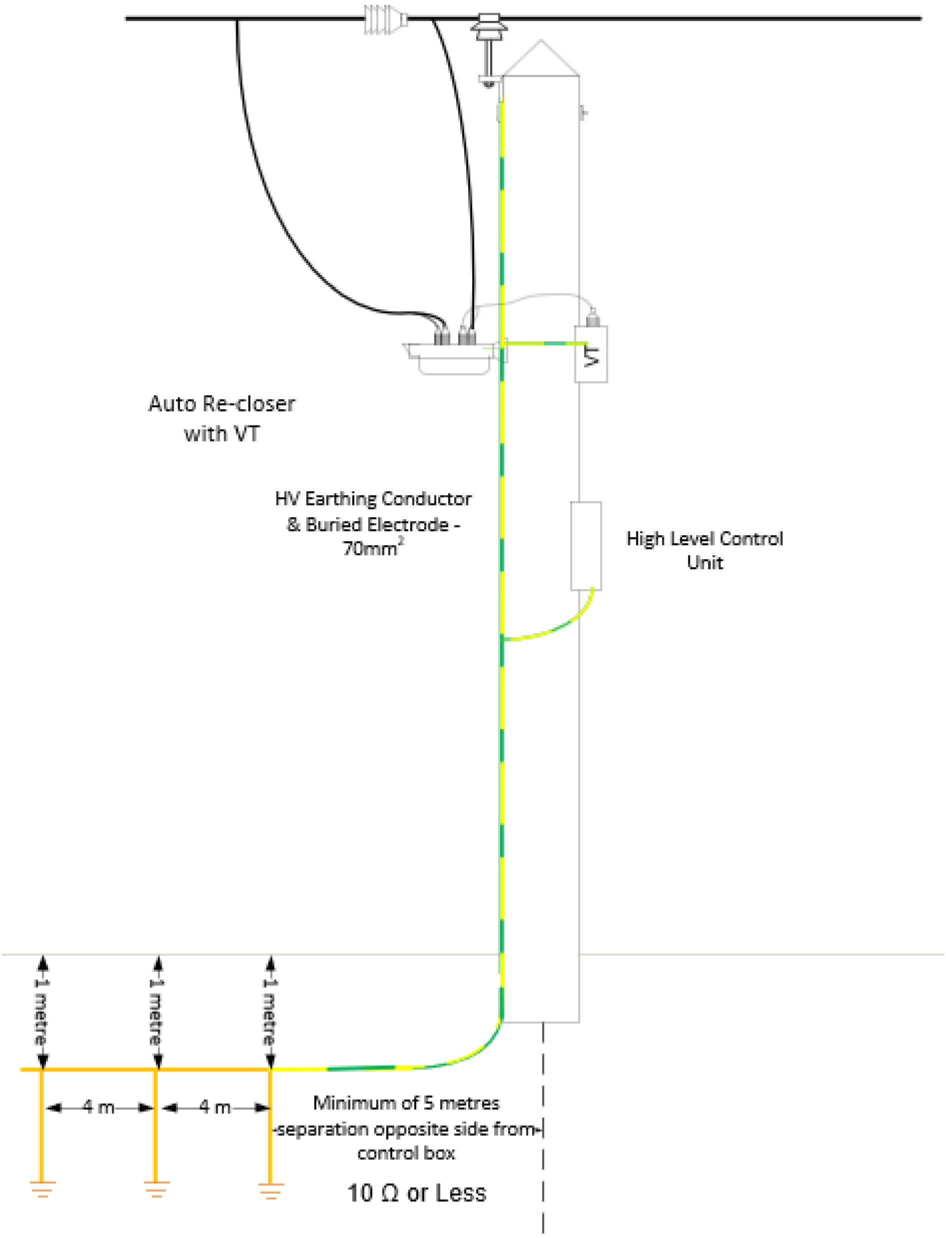


Figure 23 – PMAR with High Level Control Unit

15.8.8 Hook Stick Operated Air Break Switch Disconnector (ABSD) and HV cable

It is now permissible to install an ABSD on an earthed pole using the earthing arrangement specified in this section. Legacy air break switches need to have the earthing system reviewed as it must conform to the new earthing specification.

The *Standard Earthing Arrangement* for a hook stick operated ABSD and HV cable is shown in Figure 24.

The HV *Earth Electrode* and HV *Earthing Conductor* shall be installed as described in section 15.8.1 and shall have a maximum earth resistance of 10 Ω in accordance with section 16.7. The HV *Earthing Conductor* and *Earth Electrode* shall have a minimum cross-section of 70 mm^2.

In accordance with section 16.9, the *HV Earth Electrode* shall be installed at least 5 m away from the pole at a location where the Operator will not be standing when carrying out any live HV switching operations.

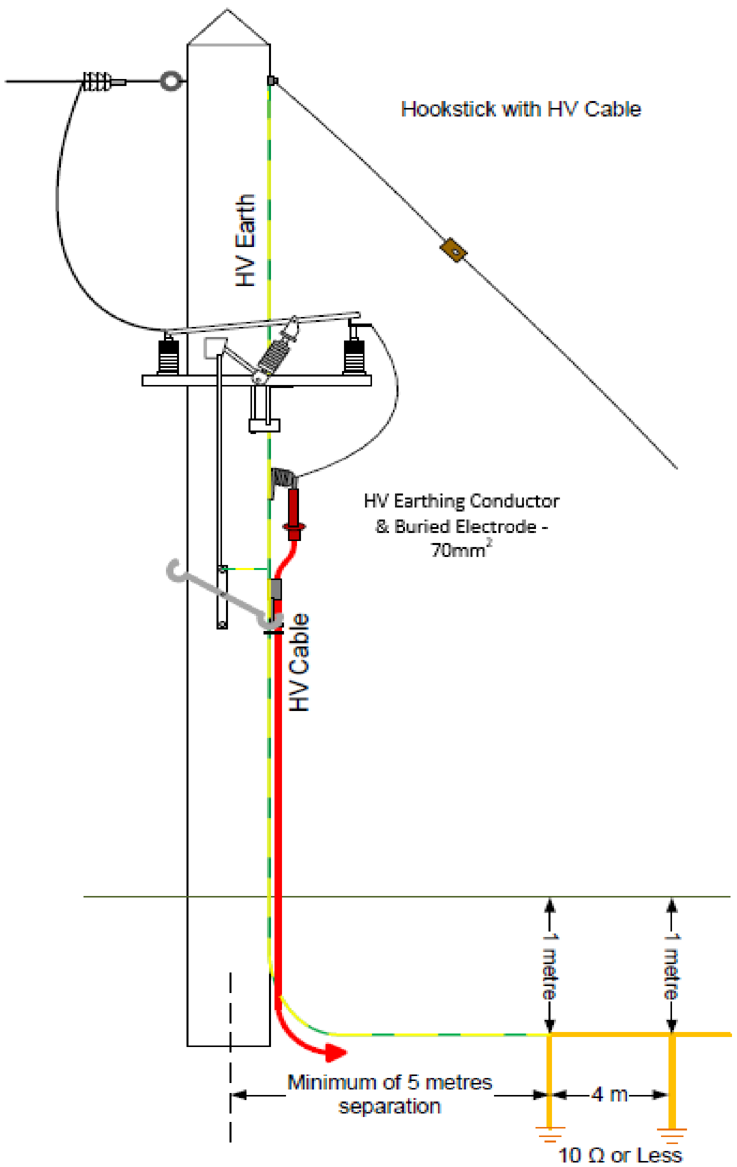


Figure 24 – Hook Stick Operated ABSD and HV Cable

16. INSTALLATION REQUIREMENTS

16.1 General

Section 15 describes the *Standard Earthing Arrangements* and associated reference drawings. This section provides additional guidance on construction aspects.

If the standard design does not achieve the *Target Resistance*, additional *Earth Electrodes* may be installed to augment the *Standard Earthing Arrangements*. Typical options include laying bare conductor in trenches or extending the rod electrodes. Where additional *Earth Electrodes* are necessary to reduce the substation earth resistance, it may be installed as follows:

i. **Extended substation earth rods**. The length of the two substation earth rods may be increased to reduce the earth resistance. This will be especially effective where the rods penetrate into a soil layer of lower resistivity, for example where they extend beneath the water table. The hardness of the ground will determine how far rods can practically be driven; where the achievable depth is limited alternative methods will be required (see below). In extreme circumstances, and where there is evidence of low resistivity material at greater depths, installation of deeper rods may be considered but will be at increased cost.

ii. **Extended horizontal *Earth Electrode***. An effective way to reduce earth resistance is to extend the *Earth Electrode* beyond the substation using horizontal electrodes buried in a trench. This may be cost-effectively achieved if the electrode can be laid beneath HV cables while excavations are available. Horizontal electrodes are typically most effective over the first two to three hundred metres. If two trenches are available (a minimum of 90º apart) then it is most effective to run two electrodes of length L in different directions than a single electrode of length 2L in one direction. Horizontal HV *Earth Electrode*s must be kept away from LV electrodes and metallic sheathed cables (by the distance specified in Table 21 for the appropriate ground mounted substation arrangement or by 20 m for pole mounted installations) if HV and LV systems are segregated (e.g. *High EPR* or *Extremely High EPR* sites).

iii. **Extended horizontal *Earth Electrode* with earth rods.** Adding vertical earth rods to a horizontal electrode can also be effective, especially where the rods penetrate into low resistivity material. Where this arrangement is employed the rods should be spaced no closer than twice their length.

If horizontal electrodes are utilised in cases of *High EPR* or *Extremely High EPR*, care must be taken to ensure the EPR is not transferred to high risk sites (see section 14) or other LV earthing systems.

16.2 *Earth Electrode* System

Buried *Earth Electrode* systems shall be of bare copper conductors, sized to meet the requirements of section 15.1 for ground mounted or 15.2 for pole mounted installations.

Where the soil is known to be acidic or alkaline (pH outside of the range 6 – 10) or otherwise corrosive to copper then the electrode shall be surrounded with 150 mm of imported neutral soil.

Joints shall be made using an Approved method. These are shown in Table 22.

Joint Type	Jointing Method
Tape to tape	Brazing or Exothermic weld
Circular conductor to circular conductor	Approved compression tool or exothermic weld
Copper to steel rebar connection	Exothermic weld or mechanical clamp wrapped to prevent moisture ingress.
Horizontal electrode to vertical rod	Exothermic weld or mechanical clamp wrapped to prevent moisture ingress.
Note: Before wrapping in Denso tape, ensure components are sufficiently dry.	

Table 22 – Jointing Methods for Buried *Earth Electrodes*

16.3 Main Earth Bar

All earth connections shall be labelled and connected via separate connections to a dedicated *Main Earth Bar* which in turn shall be connected to the earth terminal on transformers, HV switchgear and LV cabinets/fuse boards. The purpose of the *Main Earth Bar* is to help Operational personnel to determine if the earthing is intact when entering the substation, to provide a recognised earth connection/ reference point and to allow the local substation earth resistance to be measured using a clamp meter. This requirement must be balanced with theft prevention and clips / coverings / resin used as necessary to prevent unauthorised removal.

16.4 Cable Sheaths/Screen Connections

All HV cable sheaths/screens/armour shall normally be connected to the substation HV *Earthing System* to ensure the safety of operators and public. In some special situations, alternative sheath bonding arrangements may be employed as determined by the *Design Engineer*.

The standard approach in SPEN is to use three single-core cables to connect into each cable box. Each screen is connected via a bolted lug to a small earth bar inside the cable box, thus providing a robust connection. This arrangement differs from that used by many other DNOs and IDNOs (and which may be offered by switchgear manufacturers) where a single bolted connection is used for the bunched sheaths. It is important that the more secure SPEN arrangement is used because the 11 kV system in SPEN is directly earthed and *Earth Fault Current* can approach 13.1 kA unlike other UK DNOs. Standard single bolted connections are not permissible for SPEN designs as they do not offer the robustness and reliability necessary for SPEN's solidly earthed network.

16.5 Metallic Fences and Gates

New substations with metallic fences and gates shall not be installed beneath overhead line conductors. For legacy sites, the preferred approach is to divert or underground the line to remove the hazard. As a last resort, if an overhead line passes directly over the fence, fully rated conductor (120 mm^2) shall be used on the fence connections / rods 1 m either side of the crossing to account for the possibility of the overhead conductor dropping onto the fence.

The preferred approach is not to bond the metallic fence to the substation earth bar as this will export an EPR outside the substation and may cause a touch potential hazard to someone touching the fence. However, it is also a requirement to ensure safe touch potentials within the confines of the substation. Where practical, substation fences shall be constructed so that electrical hazards are designed out. This can be achieved using non-metallic fence materials or by locating the metallic fence ≥ 2 m from any earthed substation equipment as this corresponds to the maximum expected arm span of a person. Fence gates should be designed to open outwards where possible to avoid any infringement of the 2 m clearance. Sufficient space should be allocated in front of the gates to avoid opening onto the footpath or highway.

If separation cannot be achieved, any metallic fence within 2 m of substation metalwork will present a touch potential hazard. In such cases, the metallic fence shall be bonded to the substation *Earthing System* to protect anyone who has access to metalwork inside the substation. A bridging conductor shall also be installed between each set of gateposts and a flexible earth strap between the gatepost and gate. Bonding to the substation HV *Earthing System* shall be via an HV *Earthing Conductor* of minimum cross section of 16 mm^2. At *Low EPR* sites this is sufficient. At *High EPR* sites an additional horizontal *Earth Electrode* shall be installed along the full length of the fence and connected to the substation HV earth and fence. For substation perimeter fences, this electrode should consist of a ring bonded to the substation *Main Earth Bar* at two points. This should be offset from the fence by between 0.5 m and 1 m. For *Extremely High EPR* sites, a specialist design shall be carried out.

No third-party metallic fences shall be connected to the substation fence unless continuity is broken, e.g. via a 2 m section of non-metallic fence or a ‘floating’ metallic fence section mounted either end on stand-off insulators.

Due to the more onerous installation and ongoing maintenance requirements, metallic fences shall be avoided where practicable at *High EPR* secondary substation sites.

16.6 Metallic Doors

Metallic substation doors and frames shall not be bonded to the substation HV *Earthing System* at *Low EPR* sites. For *High EPR* sites, substation doors and frames shall preferably be made of wood. However, if a metallic substation door and frame must be used to provide additional security at a High EPR site, then a specialist study will be required.

16.7 Pole-mounted Installations with Surge Arresters

Unless a low impedance to earth connection is provided, the effectiveness of surge arresters could be impaired and high transient potentials can appear on the equipment being protected by the surge arrester. Surge arresters shall be sited as close as practical to the terminals of the plant, (e.g. cable termination, PMAR,PMSW). The maximum HV earth resistance shall not exceed 10 Ω for satisfactory operation of the surge arrester. (This is in line with the preferred 10 Ω value in BS EN 62305-1 for high-frequency lightning earth electrodes).

The insulated HV *Earthing Conductor* shall be installed as straight as possible down the pole avoiding sharp bends. **NOTE: where an operator may carry out HV switching operations at that pole (see section 16.9), the HV *Earth Electrode* shall be installed 5 m away from the pole**.

At pole-mounted installations with surge arresters, the *HV Earthing Conductor* and *Earth Electrode* shall have a minimum cross section of 70 mm^2.

16.8 Pole-mounted Equipment with Operating Mechanisms Accessible from Ground Level

Equipment such as PMARs, sectionalisers, and ABSDs with a low level earthed metallic control box or switch mechanisms can present hazardous *Touch* and *Step Potentials.* For this reason, these arrangements are no longer employed in SPEN and are not covered in this specification.

16.9 Pole-mounted Equipment with Operating Mechanisms not Accessible from Ground Level

It is generally considered that the probability of an *Earth Fault* occurring whilst an individual happens, by chance, to be walking across the HV *Earth Electrode* at the same time, is extremely small and therefore, in most circumstances no special precautions are required.

However, on poles with earthed equipment where an Operator may carry out HV switching operations this may create unacceptable *Step Potential* hazards should this action result in an HV *Earth Fault*. In such cases the *HV Earth Electrode* shall be installed at least 5 m away from the pole at a location where the Operator will not be standing when carrying out any live HV switching operations. Examples where this precaution is required include the following arrangements:

i. PMARs

ii. PMSWs

iii. Hook –stick operated ABSDs with HV cables

iv. HV fuse-units with HV cable

17. MEASUREMENTS, TESTING AND INSPECTION

17.1 General

Measurements and inspection are required during installation and commissioning of a secondary substation to ensure that the requirements of this specification have been met. The delivery process set out in Figure 25 below should be followed to establish that the earthing has been installed in accordance with the *Standard Earthing Arrangement* and that the *Target Resistance* has been achieved.

The *Delivery Engineer* is responsible for ensuring a standard design is appropriate. If it becomes apparent during measurement and testing that the *EPR* will be greater than anticipated at design stage, appropriate action must be taken to resolve any issues prior to energisation. The following scenarios in Table 23 may apply:

Scenario	Responsible Party		
	Measuring local *Earth Electrode Resistance*	**Measuring overall earth resistance if not a GES**	**Decision to segregate HV/LV earthing systems**
SPEN fully adopted HV/LV substation installed by SPEN	SPEN *Delivery Engineer.*	SPEN *Delivery Engineer.*	SPEN *Delivery Engineer.*
SPEN fully adopted HV customer metered supply installed by SPEN where the customer owns the HV/LV transformer	SPEN *Delivery Engineer.*	SPEN *Delivery Engineer.*	SPEN *Delivery Engineer* to advise the customer that the site is not Low EPR and that segregation of their HV and LV earthing systems is required.
SPEN fully adopted HV/LV substation installed by ICP	ICP – SPEN *Delivery Engineer* to witness tests if possible but always review results to ensure target resistance is achieved.	SPEN or ICP *Delivery Engineer* responsible for energisation to provide access to sites for ICP's competent person to carry out testing and validate EPR.	SPEN *Delivery Engineer.*
SPEN fully adopted HV customer metered supply installed by ICP where the customer owns the HV/LV transformer	ICP – SPEN *Delivery Engineer* to witness tests if possible but always review results to ensure target resistance is achieved.	SPEN or ICP *Delivery Engineer* responsible for energisation to provide access to sites for ICP's competent person to carry out testing and validate EPR.	SPEN *Delivery Engineer* to advise the customer that the site is not Low EPR and that segregation of their HV and LV earthing systems is required.
IDNO/DNO shared substation where the IDNO adopts the transformer and LV board and SPEN adopt the HV switchgear	ICP – SPEN *Delivery Engineer* to witness tests if possible but always review results to ensure target resistance is achieved.	SPEN or ICP *Delivery Engineer* responsible for energisation to provide access to sites for ICP's competent person to carry out testing and validate EPR.	SPEN or ICP *Delivery Engineer* to advise the ICP that the site is not Low EPR. ICP to discuss segregation of the IDNO's HV and LV earthing systems and action accordingly.

Table 23 – Delivery Responsibility Matrix

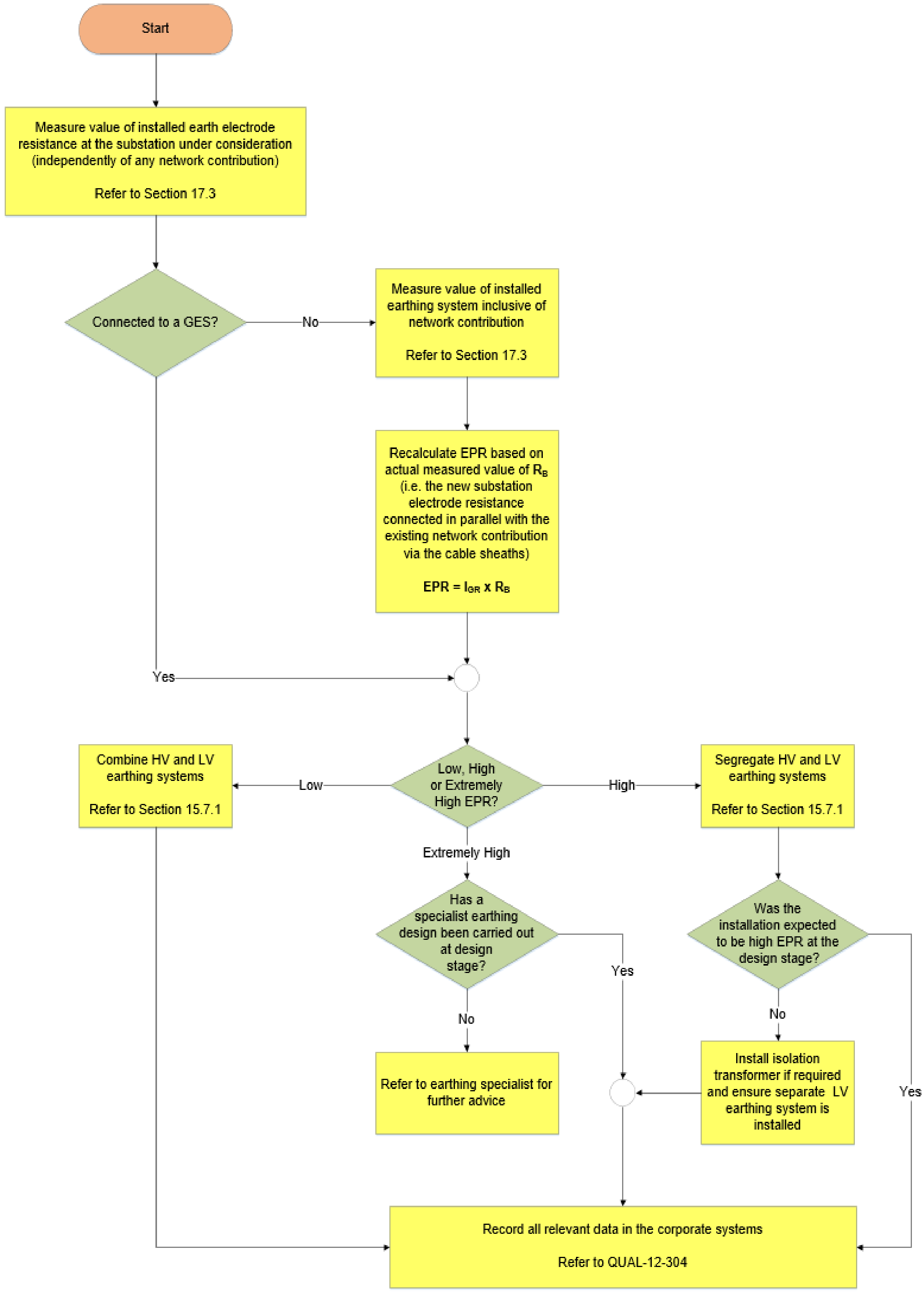


Figure 25 – Delivery Process to Confirm *EPR*

17.2 Inspection

Following installation of the *Earthing System* a visual inspection shall be undertaken by the *Delivery Engineer* to check the following aspects:

i. The standard HV *Earth Electrode* has been installed including horizontal ring electrode, earth rods, additional electrode (as required), rebar connections if applicable, *Main Earth Bar* and equipment connections.

ii. Ancillary metalwork bonded to *Main Earth Bar* including any metal doors.

iii. Correct earthing of any metallic fencing.

iv. At *High EPR* sites: The HV and LV *Earthing Systems* have been segregated and a separate LV *Earth Electrode* installed.

v. At *Low EPR* sites: The HV and LV *Earthing Systems* have been combined.

vi. At *Extremely High EPR* sites: Approved equipment, GRP enclosure and *Touch/Step Potential* control measures, as described in 15.7.4.

Any defects found shall be rectified prior to energisation.

17.3 Earth Resistance Measurement

Measurements of the *Earth Electrode Resistance* shall be made after completion of the installation to confirm that the design *Target Resistance* for the newly installed local *Earth Electrode* has been achieved.

Additionally, the value of resistance provided by the local network (i.e. *Network Contribution* shall be measured by measuring the combined overall *Earth Electrode Resistance* (i.e. the total *Earth Electrode Resistance)* of the complete installation once all HV cable sheath/screen connections have been terminated.

It is important that the measurements are carried out using industry recognised methods and equipment and results recorded. As a minimum, the following measurements shall be made:

i. Local HV *Earth Electrode Resistance* in isolation.

ii. LV *Earth Electrode Resistance* in isolation (At *High EPR* and *Extremely High EPR* sites only).

iii. Value of overall *Earth Electrode Resistance* (i.e. R_B) to confirm level of *Network Contribution*. (It is not necessary to measure this at *GES* locations (see section 10.10).

Where the measured value of local *Earth Electrode* and/or network contribution resistance exceed the design values the *Design Engineer* shall be consulted who shall confirm if criteria for standard earthing scenarios (and adoption of *Standard Earthing Arrangement*) is still valid.

18. ASSESSMENT OF THIRD-PARTY DESIGNS AND ICPS

Evidence of an adequate HV earthing design shall be provided at design approval stage. This document aims to facilitate substation earthing design for HV substations by use of standard designs in situations where *EPR* <=2.33 kV. For *Extremely High EPR* cases or high-risk areas such as petrol stations, livestock areas and wet room areas, special consideration should be given and in most cases a specialist bespoke earthing study will be necessary to plot the *EPR* contours. SPEN has developed an earthing tool to help *Design Engineers* establish the suitability of standard earthing designs (see section 13.1.3). The tool and supporting training videos are available for download via hyperlinks in the Substation Civils tab of the HV/LV Design Approval Guidance Template. This can be accessed via the SP Energy Networks website Information for ICPs and IDNOs - SP Energy Networks.

We will accept an estimated value of soil resistivity based on soil type data taken from the British Geological Survey map viewer and the associated resistivity values taken from section 5.4.1 of ENA TS 41-24.

If a standard design is appropriate, a copy of the tool populated with the site-specific data should be uploaded with your design approval binder. You should include supporting evidence for estimation of soil resistivity and *Network Contribution*. Alternatively, a copy of your bespoke earthing report from an earthing specialist should be uploaded.

For all secondary substations that will be partly or fully adopted by SPEN or where SPEN staff will be required to access, the third-party *Design Engineer* shall demonstrate compliance with the general requirements set out in this document. The third-party *Design Engineer* shall provide sufficient documented evidence for SPEN to assess compliance prior to design approval being granted.

For IDNO/DNO shared substations where the IDNO is responsible for the earthing system, the IDNO may take a similar approach to SPEN in establishing a set of their own standard substation earthing designs. If this is the case, the ICP should provide details of the expected *Touch Potential* as a percentage of *EPR*. An assessment of *EPR* as described above will also be required.

APPENDIX 1 – INFORMATION REQUIRED FOR A SECONDARY SUBSTATION SPECIALIST EARTHING STUDY

The following information will be required for a bespoke earthing study to be carried out. Explanatory notes are provided below the table, referred against the numbering in the table.

	Required Information: Minimum	**Response**
1	A suitable UMV based plan showing the proposed substation location together with any associated network alterations (underground cable / overhead line routes).	
2	Site specific soil resistivity measurement data.	
3	Where applicable, an earth resistance measurement from a substation near the proposed connection to help establish the 'network contribution' to the earth impedance. Alternatively, a geographical plan of any connected underground network to allow this to be simulated (UMV access).	
4	Single phase to *Earth Fault* current at the proposed connection point.	
5	Details of the circuit types between the source Primary Substation and the proposed connection point.	
6	*Earth Fault* clearance time for a single phase to *Earth Fault* at the proposed connection point.	
7	The EPR at the source Primary Substation (only if there is a direct underground cable connection between it and the proposed connection point).	
8	General substation layout drawing.	
	Required Information: Additional	
9	Where a more detailed assessment of transfer voltages from HV to LV earthing systems is required further details of the proposed / existing LV earthing network is required, i.e. LV cable routes and associated PME earth electrodes.	

Notes

1. This will allow the location to be determined, any site measurements to be planned and provide an overview of the proposed scheme. Proposed cable routes will be the preferred routes for any extended earth electrodes that may be required during the design. Where separated HV / LV earthing systems are required, the plan will also be used to check for adequate separation to any existing parts of the LV earthing system, properties, etc.

2. It is recommended that soil resistivity measurement data is obtained from a minimum of two locations as near to the proposed substation location as practical that is free of buried metallic services. The recommended method is the Wenner Array to a minimum of 36 m spacing and further details can be found in ENA TS 41-24.

3. Where the proposed substation will connect into an existing underground network it is useful to determine the 'network contribution', i.e. the parallel earth resistance provided by the substation electrodes, PILC cables, etc. Where practical, it can be useful to measure this at the nearest suitable existing substation using the fall-of-potential method, details of which are available in ENA TS 41-24. Network contribution can also be estimated using the assumptions provided in section 13.1.6 or by detailed simulation. The latter requires a geographical plan of the existing cable network, i.e. data from UMV.

4. To provide a realistic assessment, the *Earth Fault* current should be calculated at the proposed connection point using a suitable network model. This should include the effect of the source impedance, line impedance and earth resistance at the source and faulted substations. Use of the *Earth Fault* current at the Primary Substation will introduce overestimation of the EPR at the proposed secondary substation which may result in uneconomic overdesign.

5. Where there is an underground cable connection between the proposed substation and the source Primary Substation a significant proportion of the *Earth Fault* current will return to source via the cable sheath / screen. Details of the main underground cable sections along the route will allow the ground return current to be calculated.

6. This specification employs a standard fault clearance time of 1 s which determines the touch voltage limits that apply to the design. Where a faster clearance time can be reasonably justified, i.e. calculated based on site-specific protection settings, then higher touch voltage limits can be justified that may alleviate adverse earthing impact in some circumstances.

7. A *High EPR* during an *Earth Fault* at a Primary Substation may be transferred along the sheaths of underground cables to the proposed secondary substation, providing the cable sheaths are continuous. Knowledge of the maximum EPR at the Primary Substation allows the transfer voltage seen at the proposed substation to be calculated and allow a safety assessment. If the EPR at the Primary Substation is below the applicable touch voltage limit (or twice the touch voltage limits where there are PME LV networks) then this calculation is not required.

8. This may simply involve a reference to the SPEN *Standard Earthing Arrangement* being used. If the proposed substation is a non-standard design a general equipment layout together with a foundation layout is useful for earthing design purposes.

9. This information is only required where the *EPR* is high and it is challenging to achieve sufficient separation between HV and LV earthing systems. More detailed characterisation of the LV earthing network allows this to be added to simulations so that more accurate HV to LV transfer voltage calculations can be made. The LV network details may be available from UMV with assumptions made as to the locations of PME electrodes following SPEN installation policy.

APPENDIX 2 – EPR CALCULATION EXAMPLES

The following examples demonstrate how to perform *EPR* calculations manually for ground mounted secondary substations as opposed to using the *SPEN Distribution Substation Earthing Design Tool* (13.1.3).

A) Low EPR Calculation Example

The following example is for a new GRP close coupled substation (underground cable fed) within a *Global Earthing System* (GES) (10.10). The proposed LV *Earthing System* is separate neutral earth (SNE) and the high voltage protection clearance time is 1s.

The first step is to carry out a soil resistivity assessment for the proposed substation location (13.1.4).

Soil type is established using the British Geological Survey (BGS) website as a loam / clay mix. A value of 50 Ωm is therefore assumed from Table 6 in section 13.1.4 (Table A1 provides the relevant extract from Table 6). Soil resistivity can also be determined by using the integrated soil resistivity layer within UMV.

Soil Type	Resistivity (Ωm)
Loams, garden soils etc.	5 – 50
Clays	10 – 100

Table A1: Extract of Typical Soil Resistivity Values (Table 6 Section 13.1.4)

The second step is to establish the local electrode resistance for the GRP close coupled substation type for a soil resistivity of 50 Ωm. A value of 7.79 Ω is therefore assumed from Table 7 in section 13.1.5 (Table A2 provides the relevant extract from Table 7).

Soil Resistivity (Ωm)	Substation Type	Earth Rod Length (m)	Additional Horizontal Electrode (m)	Overall Resistance (Ω)
64	GRP Close Coupled Substation (4 earth rods, 3m x 3m perimeter electrode)	1.2	0	7.79

Table A2: Extract of Local Electrode Resistances for Various Substation Types (Table 7 Section 13.1.5)

The third step is to carry out a network contribution assessment 13.1.6 . In this example, the surrounding network is a high density HV/LV GES type system with mostly PILC SWA cable type to the north of the development and greenfield land to the south. Taking a circle of effective radius 650 m around the point of connection to the existing network and splitting this into 4 quadrants, the network contribution can be estimated using Table 10 from section 13.1.6 (Table A3 provides the relevant extract from Table 10). In this case the soil resistivity of 50 Ωm falls approximately halfway between the 32 Ωm and 64 Ωm lines in table A3. This would give an effective radius of 650 m ([500 m+800 m] / 2) and a network contribution of 0.07 Ω ([0.06 Ω+0.08 Ω] / 2) when taking account there are two full quadrants of surrounding network (those to the north and nothing in the south).

Soil Resistivity (Ωm)	Effective Area Radius (m)	Network Contribution Minimum Earth Resistance (Ω) One Quadrant	Network Contribution Minimum Earth Resistance (Ω) Two Quadrants	Network Contribution Minimum Earth Resistance (Ω) Three Quadrants	Network Contribution Minimum Earth Resistance (Ω) Four Quadrants
32	500	0.11	0.06	0.04	0.03
64	800	0.17	0.08	0.06	0.04

Table A3: Extract of 'PILC Cables – High Density & HV & LV *Network Contribution'* (Table 10 Section 13.1.6)

The fourth and final step is to calculate the EPR (13.1.7).

I_{GR} = GR% x I_F
EPR = I_{GR} x R_B

I_{GR} = Ground Return Current
I_F = Total *Earth Fault Current*
R_B = Resistance of secondary substation earth electrode in parallel with any network contribution
GR% = Percentage of the total *Earth Fault Current* which returns through the general mass of earth

Line-Ground Symmetrical RMS Fault current at 90 ms is provided by SPEN and in this case = 4.252 kA

Earth Fault Current (I_F) = 4.252 x 1.15 = 4.89 kA (includes 15% increase in fault level headroom)

% current return via ground = 30% since fed by underground cable network (70% goes back to the primary source through continuous metallic cable sheath)

Ground return current (I_{GR}) = 0.3 x 4.89 = 1.467 Ka

Local electrode resistance = 7.79 Ω (Calculated in step 2)

Network contribution = 0.07 Ω (Calculated in step 3)

Overall earth resistance (R_B) = (7.79 x 0.07) / (7.79 + 0.07) = 0.069 Ω

EPR = I_{GR} x R_B = 1467 x 0.069 = 101 V

Given that the proposed LV earthing system will be separate neutral earth (SNE) and the high voltage protection clearance time is 1s; the threshold for *Low EPR* is therefore **233 V**. The *Low EPR* limit would be 430 V if an extensive CNE/PME LV network was installed. However, in this example the SNE system means a limit of 233 V should be used.

EPR <=233 V so this is a *Low EPR* substation – LV and HV earths will be combined and a standard design for GRP close coupled subs with a perimeter earth electrode, earth rods and grading electrode under the operators standing position may be used. Measurements are required to confirm local target resistance upon installation as specified in section 17. Network contribution measurements are not required in this case as the substation is connected to a GES.

B) High EPR Calculation Example

The following example is for a new Square Double RMU/Transformer type substation (underground cable fed). The proposed LV *Earthing System* will be an extensive Protective Multiple Earth (PME) / Combined Neutral Earth (CNE) network and the high voltage protection clearance time is 1 s.

The first step is to carry out a soil resistivity assessment for the proposed substation location (13.1.4).

Soil type is established using the British Geological Survey (BGS) website as clay, sand and gravel mixture. A value of 200 Ωm is therefore assumed from Table 6 in section 13.1.4 (Table B1 provides the relevant extract from Table 6). Soil resistivity can also be determined by using the integrated soil resistivity layer within UMV.

Soil Type	Resistivity (Ωm)
Clay, sand and gravel mixture	40 – 250

Table B1: Extract of Typical Soil Resistivity Values (Table 6 Section 13.1.4)

The second step is to establish the local electrode resistance for the Square Double RMU/Transformer type substation for a soil resistivity of 200 Ωm. A value of 9.90 Ω is therefore assumed from Table 7 in section 13.1.5 (Table B2 provides the relevant extract from Table 7).

Local Electrode Resistances for Various Substation Types				
Soil Resistivity (Ωm)	**Substation Type**	**Earth Rod Length (m)**	**Additional Horizontal Electrode (m)**	**Overall Resistance (Ω)**
200	Square Double RMU/Transformer (4 earth rods, 5m x 8m perimeter electrode)	1.2	10	9.90

Table B2: Extract of Local Electrode Resistances for Various Substation Types (Table 7 Section 13.1.5)

The third step is to carry out a network contribution assessment 13.1.6. In this example, the surrounding network is a sparse HV/LV system with mostly polymeric cable type to the north, east and south of the development and greenfield land to the west. Taking a circle of effective radius 1600 m around the point of connection to the existing network and splitting this into 4 quadrants, the network contribution can be estimated using Table 15 from section 13.1.6 (Table B3 provides the relevant extract from Table 15). In this case the soil resistivity of 200 Ωm would give an effective radius of 1600 m and a network contribution of 3.25 Ω) when taking account there are three full quadrants of surrounding network (those to the north, east and south with nothing in the west).

Soil Resistivity (Ωm)	Effective Area Radius (m)	Network Contribution Minimum Earth Resistance (Ω) One Quadrant	Network Contribution Minimum Earth Resistance (Ω) Two Quadrants	Network Contribution Minimum Earth Resistance (Ω) Three Quadrants	Network Contribution Minimum Earth Resistance (Ω) Four Quadrants
200	1600	9.75	4.87	3.25	2.44

Table B3: Extract of 'Non PILC Cables – Low Density & HV & LV *Network Contribution'* (Table 15 Section 13.1.6)

The fourth and final step is to calculate the EPR (13.1.7).

I_{GR} = GR% x I_F
EPR = I_{GR} x R_B

I_{GR} = Ground Return Current
I_F = Total *Earth Fault Current*
R_B = Resistance of secondary substation earth electrode in parallel with any network contribution
GR% = Percentage of the total *Earth Fault Current* which returns through the general mass of earth

Line-Ground Symmetrical RMS Fault current at 90 ms is provided by SPEN and in this case = 2.12 kA

Earth Fault Current (I_F) = 2.12 x 1.15 = 2.44 kA (Includes 15% increase in fault level headroom).

% current return via ground = 30% since fed by underground cable network (70% goes back to the primary source through continuous metallic cable sheath)

Ground return current (I_{GR}) = 0.3 x 2.44 = 0.732 kA

Local electrode resistance = 9.90 Ω (Calculated in step 2)

Network contribution = 3.25 Ω (Calculated in step 3)

Overall earth resistance (R_B) = (9.90 x 3.25) / (9.90 + 3.25) = 2.45 Ω

EPR = I_{GR} x R_B = 732 x 2.45 = 1793 V

Given that the proposed LV earthing system will be protective multiple earth (PME) and the high voltage protection clearance time is 1 s; the threshold for *Low EPR* is therefore **430 V** which is dependent on an extensive CNE/PME LV network being installed. The *Low EPR* limit would be 233 V if there was a limited PME LV network or an SNE network was installed. However, in this example the extensive PME system means a limit of 430 V can be used.

EPR >430 V and EPR <2.33 kV so *High EPR* – LV and HV earths will be segregated and a standard design with a perimeter earth electrode, earth rods and bonded rebar may be used.

Measurements to be confirmed upon installation as required in EART-03-003 Section 17.

C) Extremely High EPR Calculation Example

The following example is for a new Square Double RMU/Transformer type substation (underground cable fed). The proposed LV *Earthing System* will be a Protective Multiple Earth (PME) / Combined Neutral Earth (CNE) network and the high voltage protection clearance time is 1 s.

The first step is to carry out a soil resistivity assessment for the proposed substation location (13.1.4).

Soil type is established using the British Geological Survey (BGS) website as clay, sand and gravel mixture. A value of 200 Ωm is therefore assumed from Table 6 in section 13.1.4 (Table C1 provides the relevant extract from Table 6). Soil resistivity can also be determined by using the integrated soil resistivity layer within UMV.

Soil Type	Resistivity (Ωm)
Clay, sand and gravel mixture	40 – 250

Table C1: Extract of Typical Soil Resistivity Values (Table 6 Section 13.1.4)

The second step is to establish the local electrode resistance for the Square Double RMU/Transformer type substation for a soil resistivity of 200 Ωm. A value of 9.90 Ω is therefore assumed from Table 7 in section 13.1.5 (Table C2 provides the relevant extract from Table 7).

Local Electrode Resistances for Various Substation Types				
Soil Resistivity (Ωm)	**Substation Type**	**Earth Rod Length (m)**	**Additional Horizontal Electrode (m)**	**Overall Resistance (Ω)**
200	Square Double RMU/Transformer (4 earth rods, 5m x 8m perimeter electrode)	1.2	10	9.90

Table C2: Extract of Local Electrode Resistances for Various Substation Types (Table 7 Section 13.1.5)

The third step is to carry out a network contribution assessment 13.1.6. In this example, the surrounding network is a sparse HV/LV system with mostly polymeric cable type to the north of development and greenfield land to the east, south and west. Taking a circle of effective radius 1600 m around the point of connection to the existing network and splitting this into 4 quadrants, the network contribution can be estimated using Table 15 from section 13.1.6 (Table C3 provides the relevant extract from Table 15). In this case the soil resistivity of 200 Ωm would give an effective radius of 1600 m and a network contribution of 9.75 Ω) when taking account there is only one full quadrant of surrounding network (only one to the north with nothing to the east, south and west).

Soil Resistivity (Ωm)	Effective Area Radius (m)	Network Contribution Minimum Earth Resistance (Ω) One Quadrant	Network Contribution Minimum Earth Resistance (Ω) Two Quadrants	Network Contribution Minimum Earth Resistance (Ω) Three Quadrants	Network Contribution Minimum Earth Resistance (Ω) Four Quadrants
200	1600	9.75	4.87	3.25	2.44

Table C3: Extract of 'Non PILC Cables – Low Density & HV & LV *Network Contribution'* (Table 15 Section 13.1.6)

The fourth and final step is to calculate the EPR (13.1.7).

I_{GR} = GR% x I_F
EPR = I_{GR} x R_B

I_{GR} = Ground Return Current
I_F = Total *Earth Fault Current*
R_B = Resistance of secondary substation earth electrode in parallel with any network contribution
GR% = Percentage of the total *Earth Fault Current* which returns through the general mass of earth

Line-Ground Symmetrical RMS Fault current at 90 ms is provided by SPEN and in this case = 2.12 kA

Earth Fault Current (I_F) = 2.12 x 1.15 = 2.44 kA (Includes 15% increase in fault level headroom).

% current return via ground = 30% since fed by underground cable network (70% goes back to the primary source through continuous metallic cable sheath)

Ground return current (I_{GR}) = 0.3 x 2.44 = 0.732 kA

Local electrode resistance = 9.90 Ω (Calculated in step 2)

Network contribution = 9.75 Ω (Calculated in step 3)

Overall earth resistance (R_B) = (9.90 x 9.75) / (9.90 + 9.75) = 4.91 Ω

EPR = I_{GR} x R_B = 732 x 4.91 = 3594 V

EPR >2.33 kV so *Extremely High EPR*. A bespoke design is required. A standard earthing design will not be possible to safely control step and touch potentials. Refer to section 12 for more details on EPR levels and limits. Refer to Appendix 1 for the information required for a secondary substation specialist earthing study.