Electricity Specification ES333

Issue 2 **December 2018**

Earthing Design for 11/6.6kV Distribution Substations and Equipment - Guidance for ICPs and IDNOs

Contents

Approved for issue by the Technical Policy Panel

Issue and Amendment Summary

Amendment No. Date	Brief Description and Amending Action
0 18/11/09	Issue 1 First Issue Prepared by: G. Bryson Approved by the Technical Policy Panel and signed on its behalf by:
- 12/10/18	Issue 2 Completely re-written in line with changes to CP333. Prepared by: P Twomey Approved by the Technical Policy Panel and signed on its behalf by Steve Cox, Engineering and Technical Director

EARTHING DESIGN FOR 11/6.6KV DISTRIBUTION SUBSTATIONS AND EQUIPMENT

FOR

ICPs AND IDNOs

1. FOREWORD

Electricity North West's previous earthing standards derived from ENA Engineering Recommendations S5 (1966), and were updated to align with ENA TS 41-24 (1992 and 2009), which superseded S5.

ENA TS 41-24 has now been updated (2018) to align with BS EN 50522 and the Electricity Safety, Quality and Continuity Regulations.

All new Earthing Systems for substations shall generally be in accordance with the new ENA TS 41-24, and these principals are applied, together with Electricity North West's operational experience and local practices, to designs/methodologies described in this document.

For distribution substations it is recognised that a full and detailed earthing design is generally impractical, and every effort has been made to avoid or minimise the need for such. This has been achieved in urban areas where, if certain criteria are met, it will be possible to install a standard design with little or no calculation effort. However, recent changes to industry standards require Electricity North West to demonstrate that a design is safe, and in some cases it will be necessary for the designer to carry out simple calculations to confirm this.

It is important that earthing is considered at the early stages of any project, particularly if a substation is to be integral to a building, since electrode may need to be installed under the building, or rebar/mesh may need to be installed in concrete screeds with the sole purpose of controlling touch voltages. Similarly, a horizontal electrode may need to be installed in open excavations; it cannot be installed in ducts etc. once excavations are back-filled. Effective earthing may be much more difficult or impossible if attempted during the latter stages of construction.

2. SCOPE

This Specification describes the requirements for the design and construction of Earthing Systems for 11/6.6kV distribution substations, detailing Electricity North West's preferred Earthing System designs where appropriate. It is intended to be used by ICPs (Independent Connection Providers) and IDNOs (Independent Distribution Network Operators), as a companion document to CP333. It applies to substations not owned by Electricity North West. **CP333 applies to substations wholly or partly owned by Electricity North West.**

The earthing design for 33kV & 132kV substations is beyond the scope of this guidance document, and is covered in CP335.

This Specification applies to all new installations in Electricity North West's distribution areas. It is not intended to be retrospective; but where work is being done on the system, the opportunity shall be taken to make modifications that will apply modern good practice to existing arrangements, where such work can reasonably be accommodated within the scope of the project.

3. INTRODUCTION

3.1 Definitions

The definitions used within this Specification are the same as those included in CP333.

Bonding Conductor	A protective conductor providing equipotential bonding.
Earth	The conductive mass of earth whose electric potential at any point is conventionally taken as zero.
Earth Electrode	A conductor or group of conductors in direct contact with, and providing an electrical connection to, Earth.
Earth Electrode Resistance	The resistance of an Earth Electrode with respect to Earth.
Earth Electrode Resistance Area	That area of ground over which the resistance of an Earth Electrode effectively exists. It is the same area of ground over which the Earth Electrode Potential exists.
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 100ms (symmetrical) RMS current to Earth, i.e. that returning to the system neutral(s) resulting from a single phase to Earth Fault. This is normally calculated (initially) for the zero-ohm fault condition. Depending on the circumstances, the value can be modified by including Earth resistance. NOTE: Not to be confused with Ground Return Current (I_{GR}) which relates to the proportion of current returning via the soil.
Earth Potential Rise (EPR) (or U_E)	The difference in potential which may exist between a point on the ground and a remote Earth. NOTE 1: Formerly known as RoEP (rise of Earth potential). NOTE 2: The term GPR (ground potential rise) is an alternative form, not used in this standard.
Earthing Conductor or Earthing Connection	A protective conductor connecting a main Earth terminal of an installation to an Earth Electrode or to other means of earthing.
Earth Mat (or Stance Earth)	A buried or surface laid mesh or other electrode, usually installed at the operator position close to switchgear or other plant, intended to control or limit hand-to-feet Touch Potential.
Earthing System	The complete interconnected assembly of Earthing Conductors and Earth Electrodes (including cables with uninsulated sheaths).

EHV	Extra High Voltage, typically used in the UK to describe a voltage of 33 kV or higher.
ENA EREC	Energy Networks Association Engineering Recommendation
ENA TS	Energy Networks Association Technical Specification.
Global Earthing System (GES)	An Earthing System of sufficiently dense interconnection such that all items are bonded together and rise in voltage together under fault conditions. No true Earth reference exists and therefore voltage differences are limited.
Ground Return Current (I_E or I_{GR})	The proportion of Earth Fault Current returning via soil (as opposed to metallic paths such as cable sheaths or overhead Earth wires) NOTE: If there is a metallic return path for Earth Fault Current (e.g. a cable screen or overhead Earth wire), this will typically convey a large proportion of the Earth Fault Current. The remainder will return through soil to the system neutral(s). Reduction factors for neutral current flows (multiple earthed systems) and sheath/Earth wire return currents may be applied to calculate the Ground Return Current. The Ground Return Current is used in EPR calculations as it flows through the resistance formed by a substation's overall Earth Electrode system (and that of the wider network) and thus contributes to voltage rise of that system. Annex I of BS EN 50522 describes some methods for calculating this component. Further guidance is given in ENA EREC S34.
Ground Voltage Profile	The radial ground surface potential around an Earth Electrode referenced with respect to remote Earth.
Hot / Cold Site	A Hot site is defined as one which exceeds ITU limits for EPR. Typically, these thresholds are 650 V (for reliable fault clearance time <= 0.2 seconds), or 430V otherwise. NOTE 1:The requirements derive from telecommunication standards relating to voltage withstand on equipment but are relevant to combining/separating HV and LV Earth systems
High Voltage (HV)	A voltage greater than 1 kV and less than 33kV. Typically used to describe 6.6 kV, 11 kV and 20 kV systems in the UK.
Main Earthing System (MES)	The interconnected arrangement of Earth Electrode and bonds to main items of plant in a substation. NOTE: formerly termed "substation Earthing System" or "main Earth grid".
Network Contribution	The electrode effect of the wide area HV (and LV) interconnected network. Large networks provide multiple parallel electrodes which can provide a relatively low impedance path to Earth.

Safe Site	A system that can maintain Touch and Step Voltages at the substation within acceptable limits during HV Earth Fault conditions.
Supplementary Electrode	An electrode that improves the performance of an Earthing System, and may increase resilience, but is not critical to the safety of the system.
Step Potential (U_S)	Voltage between two points on the ground surface that are 1m distant from each other, which is considered to be the stride length of a person
Stress Voltage	Voltage difference between two segregated Earthing Systems, which may appear across insulators/bushings etc. or cable insulation.
Suitably Qualified Staff (or Suitably Qualified Person)	Member of Electricity North West staff with sufficient experience and knowledge to undertake detailed earthing design, including calculation of Ground Return Current / sheath current, fault current and EPR.
Target Resistance	The Earth resistance, of the substation electrode system determined by policy or design, necessary.
Touch Potential (U_T)	Voltage between conductive parts that can be touched simultaneously, or between one part and the ground/floor where a person might stand, typically 1m from the equipment.
Urban network	A mature network which includes existing cable installations as well as other, metallic utilities, in a built up area with a radius of at least 1km around a particular site.

3.2 General

This document describes how third parties (ICPs and IDNOs) can achieve compliance with Electricity North West requirements with regard to electrical earthing in small 6.6kV and 11kV substations and switchrooms / metering rooms. It is based along the same principles as Electricity North West's Code of Practice (CP333), which provides a means of complying with Electricity North West's earthing policy EPD333 "Supply System Earthing".

This Specification also provides guidance for safe design and construction of earthing systems for customer demand and generation connections where the customer carries out the majority of the design and construction work, and includes specific guidance for solar and wind farms.

This document is not a substitute for specific design and construction standards but has been produced to assist Electricity North West staff and customers with relevant aspects of a connection application.

The customer (or IDNO's) own installation will generally be designed and built by the developer with reference to appropriate standards. It is not Electricity North West's role to carry out design work for a developer. However, Electricity North West does have a duty of care to ensure that the earthing system of any customer/IDNO connected to its distribution network is adequate in terms of safety and conforms to relevant UK earthing standards.

An audit of the earthing design shall be carried out to ensure that the design meets relevant Electricity North West and UK standards as described in this document. All earthing designs shall be approved before construction, and tested before energisation.

Connection will be refused, as outlined in Paragraph 26 of the Electricity Safety Quality and Continuity Regulations (ESQC Regulations) 2002, if Electricity North West considers a design to be unsafe.

4. POLICY SUMMARY

The guidelines in this document apply to the earthing of any substation associated with customer demand and generation connections at 6.6kV and 11kV. Typically these fall into two categories:

1) Those to which Electricity North West staff have access, such as metering substations or shared 11kV switch rooms, or any other areas which are to be adopted by Electricity North West;

2) Those which are customer or IDNO owned, to which Electricity North West staff do not have keyholder access.

The former (1) substations SHALL be designed in accordance with Electricity North West standard CP333 (as summarised below), and thus will provide safety to operators within the substation as well as minimising risk outside the substation.

Customer or IDNO substations (2) must be SAFE* (and must not cause issues beyond their immediate areas) but need not be constrained to Electricity North West practices.

* NOTE: The term 'SAFE' in this context relates to touch, step and transfer voltages which are 'SAFE' if they are within permissible limits, and thermally rated to prevent fire/failure during passage of normal earth-fault current.

Refer to Sections 5 (Overview) and 6 (Detail) for a description of earthing design principles.

5. OVERVIEW

5.1 General

Earthing is necessary to ensure safety in the event of a fault.

In general terms, the installation should be connected to the general mass of earth via an electrode system that provides a suitably low earth resistance value. In the event of an earth fault, the earth resistance needs to be low enough to limit the Earth Potential Rise (EPR) to safe values and to operate the earth fault protection. It also needs to be capable of carrying, without damage, the fault current that will flow until the system protection can operate.

In addition, bonding (low impedance connections) is required between equipment and metalwork to ensure they remain at the same voltage and to safely convey fault current without damage or danger.

5.2 Basic Principles

During an earth fault, the voltage of the earthing system and everything connected to it rises briefly until the protection can operate to clear the fault. Effective earthing and bonding minimises the risk to staff and public during this time.

The magnitude of the voltage rise (EPR) is determined by the resistance of the local electrode system (R_b) and the fault current that flows into it (I_{ef}). Typically, for overhead systems, almost all of the earth fault current will return to the source via the ground. For cable systems, the ground return current (I_{gr}) will be much smaller if the cable sheath provides a continuous metallic path back to the source substation. The ground return current percentage (I_{gr}%) can approach 100% for overhead systems and is typically 5% to 30% for cable systems. The designer should work out the worst case (highest) I_{gr} figure* for different running arrangements using a suitable tool, or by reference to formulae in ENA ER S34. He/she will require knowledge of the cable circuit(s) including sheath types and cross sections to do this. Electricity North West will provide cable data (or an estimate of I_{gr} for different values of R_b) on request.

* NOTE: An exception exists in dense urban areas, where (if certain conditions are met) the installation is said to form part of a Global Earthing System (GES). This is described in Section 6. If a system is GES, a standard Electricity North West arrangement may be installed without further calculation.

For most Electricity North West systems, the earth fault current I_{ef} is limited by reactors connected to the transformer star points at the source substation; typical maximum earth fault current values are I_{ef} = 2kA for 2 transformer substations and 3kA for 3 transformer sites. Electricity North West will provide this data to the ICP/IDNO to enable design calculations to proceed.

The application of Ohm's Law gives the EPR:

$$EPR = I_{ef}\,(A) \times I_{gr}(\%) \times R_b(\Omega)$$

NOTE: EPR should be considered for all voltage levels (except LV) at a substation. Transfer potential from another substation can also cause an EPR – see 5.4 below.

In designing an electrode system, the value R_b should be low enough to limit the EPR (and touch/step) voltages to safe values (see below). R_b is termed the 'Target Resistance' of the substation and is further described in 6.5 below. The maximum allowable EPR on any Electricity North West adopted substation is:

Table 1: EPR Limits for 11kV and 6.6kV Substations in Electricity North West Areas

Site designation	Maximum EPR limit *
Hot	2 kV
Cold	430 V

* NOTE: This is not the same as **touch voltage limit** – see 5.3 below. The 2kV limit ensures standard Electricity North West designs are Safe with respect to touch voltages. Higher EPRs are permissible but will require bespoke studies to ensure safe

A Cold site is preferred where possible – See Section 6.8.

A Hot site is permissible in some circumstances and may offer some design economy, but additional measures are required to ensure safety and to prevent dangerous transfer voltage to LV networks. In some situations a Hot site will not be acceptable if it is in close proximity to Electricity North West's network, or if is to supply a network where HV and LV earthing are already combined. These issues should be discussed with Electricity North West and a solution agreed before opting for a Hot site design.

The overall value of R_b will usually reduce when the customer's system/third party network is connected to the Electricity North West system, but the Electricity North West substation(s) should be safe without reliance on this contribution:

The customer's system shall be able to operate safely should it become disconnected from Electricity North West's earthing system and vice-versa.

In some situations this may not be practical or economic to achieve, in which case agreements need to be in place to ensure the ongoing integrity of (and to permit testing of) any shared earthing system components.

5.3 Touch and Step Voltages

Touch and step voltages can be calculated using software or standard equations and for any given design they are a fixed percentage of the EPR. For Electricity North West standard arrangements the values of Touch% are tabulated in CP333. For any non-standard layouts to which Electricity North West staff have access, Electricity North West will need to see computer modelling of voltage contours to satisfy that Touch% values are equal to, or less than the appropriate Electricity North West layouts.

NOTE: For urban areas where Global Earthing System (GES) requirements apply, the substation must achieve Touch% of 10% or less. Electricity North West standard layouts should be used in these areas. In exceptional circumstances, alternative designs may be agreed with Electricity North West. In all cases EPR × Touch% must be less than the appropriate 1 second limit for touch voltage (233V on soil or 298V on dry concrete).

Except for GES situations, touch voltages should be calculated inside and outside of the substation/switchroom(s), as well as around any metalwork (including fences, building structures, cladding etc.) which is connected to the earthing system.

Acceptable touch and step voltages are dependent on the fault clearance time and surface covering. The fault clearance time should be taken as 1 second (unless otherwise advised by Electricity North West) if controlling circuit breakers and/or relays are owned/operated by Electricity North West.

IDNOs / Private network operators may design their system to different (faster) protection clearance times if this can be reliably achieved with IDNO/Privately owned and operated circuit breakers (i.e. at or downstream of the point of supply). The network operator shall confirm in writing that touch voltages within his/her network comply with those given in ENA TS 41-24 (2018), which in turn derive from BS EN 50522 (refer to Section 10, Documentation).

NOTE: Earthing systems for substations supplied directly from an overhead line network (under normal or abnormal running conditions) may require additional precautions (e.g. additional ring electrode and/or a concrete or tarmac surround) to achieve acceptable touch and step voltages.

5.4 Transfer Voltage

(Refer to Fig.1)

For cable connected systems, a fault at the source substation (i.e. Electricity North West's primary or grid substation) can produce an EPR at the new installation due to voltage rise being carried along the cable sheath.

This 'transfer voltage' should be calculated only if the source substation is Hot and within 500m of the new substation. If the transferred EPR is greater than that for local faults, then touch/step voltages for this condition must be compared to acceptable limits based on the EPR(s) and fault clearance time(s) at the source substation.

Transfer voltage can also be an issue if remote references (e.g. telephone cables, cable TV systems, water pipes etc.) are brought into an installation, since these will nominally be at or close to zero volts (true earth potential) and should be considered where any unbonded services exist within the site boundary or close to it. Measures should be in place to prevent hand-to-hand contact between HV steelwork and these remote references (barriers, separation, or bonding as required).

Transfer voltage calculation requires knowledge of cable sheath impedance for the whole circuit, and the new substation's electrode impedance (resistance). It can be reduced by lowering R_b, i.e. enhancing the electrode system at the new substation, this will promote a larger voltage drop in the cable sheath.

NOTE: In some situations an insulating gap (insulated cable gland, or a section of overhead line) can be introduced to prevent transfer along a cable sheath; these measures, if needed, must be discussed with Electricity North West before proceeding as they can introduce problems such as shock risk across a gap, or operational/maintenance issues).

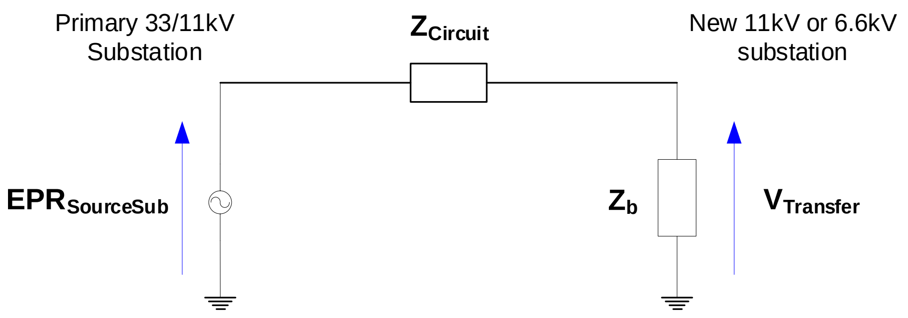

Fig. 1: Transfer Voltage from Source

$$V_{Transfer} = EPR_{SourceSub} \times \left(\frac{Z_b}{Z_{Circuit} + Z_b}\right)$$

If transfer voltage exceeds 430V then the substation must be classed as Hot and HV/LV earths separated in line with normal practice (see 6.8).

6. DESIGN PRINCIPLES

6.1 Design Criteria

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

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

The main objectives are to:

1) Design and install an earthing system that provides sufficient safety with regard to touch and step voltage limits.

2) Conform with the requirements of UK earthing standards, namely BS EN 50522, ENA TS 41-24, and (for customer systems) BS 7430; and

3) Satisfy Electricity North West that the site is safe to energise and operate.

6.2 Approach

Electricity North West's approach to earthing design for secondary / distribution substations is no longer based around the '1 ohm rule', and instead is based on a simplified earthing design methodology as described below.

ICPs/IDNOs will be expected to follow a similar process, as described in ENA TS 41-24 (2018) Chapter 9, for shared / Electricity North West accessible substations.

In the first instance, any new installation is assessed for whether it meets the criteria for a GES, as shown in Table 2 below. If the installation is part of 'GES' (i.e. all tick boxes are checked), a standard substation layout and electrode resistance may be installed without further calculation, provided the substation earthing design meets certain criteria. Guidance shall be sought from Electricity North West if it is unclear a GES exists.

In all other areas it is necessary to calculate the EPR, and Touch / Step voltages that can appear under fault conditions, and to confirm that these are within permissible limits.

Electricity North West will provide all necessary data to an external connection provider to enable a safe earthing design to be produced (See Section 9).

Table 2: Substation Types

Category	Characteristics	
Type 1 (Global Earthing System requiring no further assessment)	Needs to satisfy all of the following criteria:	
	Ground mounted……………………………...............	☑
	All-cable fed ……………………………………………	☑
	Part of a large (>1km radius) urban network…............	☑
	Local average soil resistivity 300 Ω.m or better ………	☑
	Impedance earthed source substation (max. 2kA Earth Fault Current).……………………………………	☑
	Cold source substation with resistance < 0.17 Ω (or measured Network Contribution < 0.17 Ω)[‡] …………	☑
	Standard Electricity North West substations (or exceptionally other design approved by Electricity North West) without metal fences / enclosures (inc Compact/Pad mount designs), in Glass Reinforced Plastic (GRP) (or integral to building) with modelled Touch% <=10%…………………...............	☑
	These sites do not require detailed assessment. See also Section 5.4.1 of CP333 for more detail.	
Type 2 (Basic Assessment)	Anything that fails the tests for Type 1 above (i.e. any un-ticked boxes). These sites require a basic assessment (Section 5.4.2 of CP333). If the basic assessment reveals an EPR[*] > 2kV, or other problems, the site may fall into the Type 3 category as below.	
Type 3 (Detailed Assessment)	Those where a basic assessment reveals an issue. These generally will require a detailed assessment including modelling. Such sites normally have one or more of the following: Solidly earthed primary substation / Some or all overhead line / poor or shallow soil (>300 Ω.m) / Rock / difficult ground conditions / Little or no nearby network / Nonstandard substation / Metal fences or pad-mount.	
* EPR – Earth Potential Rise ‡ This requirement will normally be satisfied if the 'network area' and 'soil resistivity' boxes are ticked		

Earthing designs shall be compliant with ENA TS 41-24 (2018) and BS EN 50522.

Customer installations shall comply with BS 7430 (HV earthing) and BS 7671 (LV).

IDNOs/Private network operators are recommended to follow the same approach but ultimately are not limited to the standard Electricity North West designs and may install any layouts they wish, provided they can satisfy Electricity North West that the design is safe and will not cause issues within or outside the substation (including on the wider HV or LV network). In this regard, the touch voltages, step voltages and transfer potential (to the LV system or any third party installation) must be within permissible limits based on 1 second fault duration.

Electricity North West has a duty of care to ensure that unsafe installations are not connected to its network, and to ensure that staff (who may be working in or around IDNO substations) are not subject to unacceptable risk.

6.3 Design Requirements

Substation earthing provides the following function:

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

To satisfy this, the following design requirements shall apply for ground mounted installations:

1) A maximum HV electrode (including supplemental horizontal electrode) earth resistance of **10Ω** to operate the HV protection.

2) A maximum earth potential rise of 2kV.

3) Touch and step voltage control – typically a ring electrode enclosing and bonded to all equipment and rebar bonding (or stance earth mats) to ensure the touch voltages are within acceptable limits.

4) Earth electrode sizes based on source earth fault levels.

5) The earth potential rise limited to 430V as far as reasonably practicable (provided the HV protection operates within 1 second for faults at the substation), to allow the HV/LV earths to be combined and prevent dangerous voltages appearing on the LV system; if this limit cannot be satisfied the HV/LV earths shall be separated.

6) A maximum LV earth resistance of 20Ω (in accordance with ENA ER G12) where a separate LV earth is required.

7) Touch voltage shall be within acceptable limits using the substation electrode system alone[1] where possible, and shall not rely on any parallel contribution from Electricity North West network.

8) The proposed earthing system must be practical to achieve on-site to avoid re-design at the time of installation.

Electricity North West Standard ‘10%’ Arrangements for GES areas achieve these requirements without detailed design calculations provided the conditions for GES/Type1 installations are satisfied (Table 2 above).

6.4 Electricity North West Standard Substation Layouts

Electricity North West / ICP installations shall adopt one of Electricity North West’s standard arrangements. These are described in CP333 Section 6 and Appendix A. Crucially, each substation uses a combination of rod electrodes, ring (perimeter) electrodes, and rebar bonding to control touch voltages within the substation area.

[1] To ensure the touch and step voltages within and around the substation are safe for the expected life of the substation no matter how the network changes.

Those designs that are suitable for GES applications achieve a touch voltage that is less than 10% of the overall earth potential rise (EPR). Other designs shall not be used in GES areas except with the written approval of Electricity North West; these shall be those where computer modelling has been carried out to the satisfaction of Electricity North West which demonstrates a Touch% value <=10% inside the substation area, and prevents contact from outside.

Standard layouts may need to be augmented / improved by addition of electrode, either laid horizontally, or in the form of driven rods. This is necessary to achieve a given target resistance (see below) depending on the local soil type (more electrode is required in high resistivity soil).

The resistance of additional electrode(s) may be modelled using computer, or calculated using formulae in ENA EREC S34 (2018), or BS 7430. This will require knowledge of soil layers and resistivity.

See also Section 7.

6.5 Target Resistance

The target resistance necessary shall not exceed **10 ohms for ground mounted installations**, and may need to be significantly lower.

Electricity North West will provide either:

1) Confirmation that the location is suitable for a standard earth mat as defined in CP333), or:

2) Earth fault level information and network contribution estimates, and other data necessary (e.g. cable types) to allow a designer to arrive at a target resistance value or to make an assessment of whether GES conditions apply.

With the exception of GES, ultimately the designer will need to calculate the ground return current I_{GR} for all running arrangements, and multiply this by the electrode resistance (R_B) to find the EPR of the site, using information provided by Electricity North West. The design is a recursive procedure (since altering R_B alters I_{GR}) but will eventually converge on a value that will achieve safety, and if appropriate, a Cold site.

Safety (touch and step voltage) calculations should not include network contribution (see below), but overall operational EPR may be evaluated (to determine Hot/Cold status) for normal running arrangements with network connections intact.

HV electrode resistance **MUST NOT exceed 10 ohms for ground mounted installations**, this is the highest possible value that will permit reliable protection operation on Electricity North West's system. Electricity North West will provide protection settings on request. Note that Electricity North West's secondary protection, if any, is usually ignored for the purposes of earthing design since this can be switched out or non-functional. IDNOs / Private network operators may include secondary protection in earthing calculations if this is under their control and deemed to be reliable (e.g. multi-panel 11kV switchgear 'downstream' of metering position). Exceptions shall be agreed by the Head of Safety and Policy, Electricity North West.

6.6 Rebar / Piles

Rebar / Piles may be connected to a substation main earthing system and will reduce the resistance achieved as well as providing redundancy. The dedicated (copper) electrode system should be sufficient to achieve safety without reliance on Rebar/Pile contribution where possible.

If it is necessary to rely on contributions from piles etc., the connections shall be duplicated to ensure reliability and calculations performed to verify that the rebar will not overheat during passage of fault current. With vertical piles it may be possible to install fully rated copper tape electrodes during installation, in which case these may be treated as encased rod electrodes and no further calculations are required. Only copper / dedicated electrode should be included in surface area calculations; steel rebar and other fortuitous or auxiliary electrodes should not be included in normal circumstances.

6.7 Network Contribution

Electricity North West substations (or those adopted / operated by Electricity North West) shall be SAFE without network contribution but assuming that the cable sheath is intact from source to substation.

If achieving a safe site in isolation is difficult (e.g. unusually high fault levels and/or high ground return current, perhaps due to presence of overhead line or poor conductivity cable sheaths, high resistivity soil, etc.), the contribution from the network may be considered only if connections are duplicated (i.e. the substation is looped rather than teed) and reliable. This approach should be used only as a last resort and justified in design documentation. Ongoing safety of the site then relies on an intact and low impedance cable sheath connection(s) to the neighbouring network.

Similarly, customer substations should, where possible be safe without relying on an earth connection to Electricity North West's substation (see also 5.2). In difficult situations, customer sites may rely on Electricity North West's contribution (and vice-versa) provided every effort is made to protect the integrity of bonds throughout the lifetime of the installation.

Network contribution may be estimated by treating lead sheathed cables as horizontal conductor radiating in 2 or 3 directions from the substation (being careful not to include areas of overlapping influence) – this is best modelled using a computer.

6.8 Hot/Cold Status

Electricity North West substations should be made Cold where possible, in which case the Earth Potential Rise will not exceed 430V. Substations that qualify as GES will naturally achieve this in urban areas.

If a Cold site cannot be achieved, a Hot site is permissible, for which the ultimate upper limit for EPR at any substation is 3kV. However, note that a Hot site may not be appropriate in all situations. For example, a Hot site should not be installed:

1) Connecting into a local network where lead sheathed HV and LV cables are in close proximity, i.e. one which operates with HV/LV links in place at existing substations and that is nominally Cold.

2) Close to areas where the high EPR could be hazard or could cause damage. These sites include gas/oil refineries, petrol stations, outdoor swimming/paddling pools, near railways/signalling equipment, telephone exchanges etc. (this list is not exhaustive).

Additional precautions are necessary to ensure the HV EPR does not cause an issue on LV networks. HV and LV earths must be kept separate, by an appropriate in-ground distance to limit EPR transfer to LV under HV fault conditions. The two earthing systems shall be segregated by a distance sufficient to place the LV electrode(s) outside the 430V contour, and to withstand a 'stress voltage' of 3kV (or the EPR of the site, whichever is higher). Care is required if bringing LV supplies into the Hot site, and for any cable sheath connections into/out of the Hot site, including metering wiring and capacitor/emergency trip units.

Electricity North West will specify additional measures that are required to ensure ongoing separation, including the use of isolation transformers etc. where LV supplies are required to RTU units or similar. Refer to CP333 Section 5.5 and C7.

IDNOs / Private network operators may, if they wish, operate at higher EPRs up to full line voltage, provided safety to personnel and public can be demonstrated by use of appropriate computer modelling or calculations. In particular, touch and step voltages must be safe for protection clearance times of 1 second. It will usually be necessary to enclose such substations in GRP enclosures to reduce risk to the public, and to use surface mesh earths / plates around switchgear. Care is needed with electrode placement to minimise step voltage risk to public and livestock. RTU / trip / metering circuits require extreme care to prevent the export/import of dangerous potential differences. LV systems leaving such 'extremely high EPR' substations must be suitably insulated (and ducted if necessary) to prevent HV-to-LV flashover under fault conditions. This will normally require manufacturer's verification in the form of test certificates for the transformer windings, bushings, and transformer mounted fuse cabinet etc.

The Hot/Cold site classification is immediately relevant to (third party) communications infrastructure. The details of any Hot site shall be sent to Electricity North West so that they can be recorded in the asset register. BT Openreach (or another telecommunication company) may also need to be notified if their assets are nearby. Other third parties (such as pipeline operators) also have an interest in this information, and should be consulted if Hot substations are within 50m of their assets.

7. ELECTRICITY NORTH WEST STANDARD LAYOUTS

Refer to CP333 for a comprehensive list together with tabulated characteristic values.

Standard layouts include the following features:

- A buried ring electrode around the site or an embedded mesh to control the touch and step voltages.
- A marshalling bar for all earthing connections.
- Additional rod or horizontal electrodes, as necessary, to reduce the resistance to achieve the calculated 'target' value.
- A non-conductive enclosure to prevent contact from outside the substation.
- Equipotential bonding as necessary to minimise hand-to-hand risk inside the substation.

Third party substations will usually follow similar guidelines.

8. CONDUCTOR AND ELECTRODE SIZING

Conductor sizing must be rated to withstand maximum earth-fault current (3kA or otherwise as advised) for 3 seconds. Buried conductors must be copper and (if stranded) with a minimum strand diameter of 2mm to resist corrosion.

Conductors need not be sized for phase-to-phase fault levels except where:

1) single phase switchgear is separately earthed to a main earthing system, or otherwise if there is a foreseeable risk of phase-to-phase fault current flows, or

2) some systems protected by Arc Suppression Coils (ASC), where the coils can be switched out (to solid earthing) for maintenance, or there is otherwise a possibility of cross-country (phase-to-phase) faults.

There is one ASC system in Electricity North West, but this is currently disconnected (Penrith Newtongate Primary S/S).

Except in GES areas, electrodes must have sufficient surface area to carry full ground return current (I_{GR}) for 3 seconds. This requirement aims to prevent soil drying out, and may be relaxed to 1 second with Electricity North West's authority in most areas based on operational experience.

9. DATA (TO BE PROVIDED BY ELECTRICITY NORTH WEST)

The following information required to design a secondary substation earthing system shall be provided by Electricity North West:

- Source grid/primary substation earth fault level and earth resistance value.
- Earth fault level at the new secondary substation or Point of Connection.
- Source substation classification (Hot/Cold) and the associated earth potential rise for Hot sites.
- Source substation resistance value, and soil resistivity layer model measured during most recent survey if available.
- Details of the cable or overhead line network between the source and the new secondary substation including lengths, types, and the cable sheath cross-section and material (where appropriate) etc.
- Source substation location for calculating the distance to econdary substation..
- Fault clearance time for an earth fault at the new substation (or standard value).

10. DOCUMENTATION (TO BE PROVIDED TO ELECTRICITY NORTH WEST BY ICP OR THIRD PARTY)

For all earthing installations used for distribution substations, Electricity North West require the following documentation, usually in the form of an earthing report accompanied by drawings and photographs, followed by on site measurements.

Earthing design submissions that do not include sufficient information or that do not meet the minimum requirements of this Specification shall not be granted Electricity North West approval.

10.1 Earthing Report

The report should contain, as a minimum:

1) Designer name and contact details / affiliation.

2) Site name / number and address.

3) Point of connection and point of supply (if different).

4) List of data provided by Electricity North West, and/or assumptions made relating to fault currents, protection operation time and settings, cable / circuit type and sections, source substation EPR and earth resistance reading (R_A), estimated ground return current, normal and alternate running arrangements (if known), soil resistivity / layer models used.

5) Drawings showing electrode layout and locations (see below), or confirmation that a standard Electricity North West or IDNO design has been used.

6) Computer modelling results (showing Touch% in and around the substation, and Step if associated with livestock) if substation layout is not a standard Electricity North West arrangement.

7) Calculations / checks saying whether GES applies or EPR and touch/step/transfer voltages for faults at all voltage levels (where applicable, excluding LV).

8) Design 'target resistance required' (or 10 Ω for GES).

9) Confirmation of Hot / Cold status, and plot/calculations showing radius of Hot zones (1700V, 1150V, 650V and 430V contours).

10) A layout drawing showing the location of LV electrode(s) close to the substation, and confirmation whether HV and LV systems are combined or separate.

11) For IDNOs or private networks, written confirmation that these substations (to which Electricity North West do not normally have access) achieve safe step and touch voltages inside and around the substations, and that transfer voltages to LV are acceptable. Designer to specify which design standards have been used for the installation* and location of / ownership details of relevant protective devices if these are not Electricity North West owned and are required to ensure safety.

   *NOTE: Designs to American IEEE80 will not be acceptable.

12) Design detail including

- Base data and source.

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

10.2 Earthing Drawing

An earthing arrangement drawing shall include as a minimum:

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

10.3 After Completion / Commissioning

Once the site is built, and electrode installed / backfilled, the earthing performance must be measured compared to predicted design values. The fall-of-potential test is most appropriate for measurement of electrode resistance in areas where there is access to open land – refer to ENA TS 41-24(2018) Measurement section, or CP333 Appendix E for guidance on measurement techniques.

After completion, ICP / Designer to provide Electricity North West with:

1) A record of measured HV and LV electrode resistances (before connection of HV and LV cables), and (if carried out) overall resistance values (after connection of HV cables).

2) If a clamp meter is used around connections to a marshalling bar or individual rods, a record of its reading(s) should be kept so that any future variation can be observed.

3) Photograph(s) of completed substation(s).

This testing may form part of Electricity North West's commissioning / audit process but will normally be carried out by the ICP/Designer or his/her agent. Electricity North West will advise whether Electricity North West wishes to undertake / oversee measurements.

11. INSTALLATION REQUIREMENTS

11.1 General

Standard industry good practice is expected, as outlined in ENA TS 41-24. In particular:

- Horizontal electrode must be in contact with bare soil. It must be buried at least 0.5m from the surface. If surrounding equipment/plant/fences it should be 0.5m to 1.0 m from the plant so that it naturally sits underneath any person touching that plant.

- Do not backfill with sand or similar material (e.g. crushed glass) which may insulate the electrode from the surrounding soil.

- Conductive concrete compounds may be used as a theft prevention method. Where possible, radial HV electrodes shall be laid underneath incoming HV cables to provide a degree of protection against theft and damage.

- LV electrodes should be laid below LV cables for the same reason.

- Rod electrodes may be mechanically driven, or (depending on rod length and ground conditions) may be installed in a pre-drilled / augered hole. In this instance the hole should be backfilled with bentonite or similar conductive slurry compound which will improve electrode efficiency.

- Chippings, if used, provide a layer of insulation and should be at least 75mm deep and kept free of weeds.

- Asphalt (tarmac) may be used in place of chippings, and can increase safety at the same time as reducing maintenance.

NOTE: The designer may mandate the use of asphalt in some instances where it is difficult to achieve a safe site otherwise. It should be 100mm thick if used as an insulating layer (i.e. to allow higher touch voltage limits). Its use for this purpose is discouraged, i.e. other measures should be explored to make a substation safe without reliance on asphalt, simply because the insulation properties of any ground covering could become compromised by cracking / aging and weed growth.

- Only copper electrode or copper clad electrodes shall be used below ground.

NOTE: Stainless steel may be used in some circumstances with permission of Electricity North West.

- Above ground conductors may be aluminium to save cost and to provide some protection against theft. Approved transition joints (to copper) shall be used where necessary, suitably protected from moisture ingress.

- Copper tapes / rods may be joined using exothermic welding or mechanical clamp / crimp connections wrapped or protected to exclude moisture. Dissimilar metals should not be used due to the likelihood of electrolytic corrosion (e.g. steel clamps on copper tapes) etc.

- All earth conductors shall terminate on a marshalling bar inside the substation, in a manner to facilitate testing and identification of conductors.

- Cable sheath connections shall be secure and (ideally with triplex/single cores) each sheath made off onto separate lugs rather than bunched into one lug, to avoid the likelihood of a single point of failure. Cable boxes with small earth marshalling bars are available for this purpose and offer greater resilience than a single stud.
- Connections to Earth Electrodes should be by means of compression fittings or bolted clamps complying with BS 951. Other methods of connection can be used where specifically approved. Refer to CP411LV for further detail.
- Below ground connections shall be suitably protected against corrosion, typically greased and wrapped in bitumastic tape or similar to exclude moisture, or using proprietary heat-shrink/glue methods as approved by Electricity North West. Exothermic welding may not require additional protection; the advice of the manufacturer or Electricity North West's expert should be sought.

11.2 Equipment Bonding

All current carrying items of equipment including the HV switchgear, LV pillar/cabinet/board etc. shall be bonded to the transformer (or switchgear) earth terminal using an independent connection. The minimum size of the bonding conductors is **70mm^2** stranded copper or equivalent, or otherwise as advised by Electricity North West.

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

Items of plant, RTU cabinets, etc. shall be bonded to the substation HV Earthing System, usually by a labelled connection to a dedicated marshalling bar. This bar is shown on the drawings for each Electricity North West standard design. The bar facilitates testing by use of a clamp meter and is not intended to be unbolted in service.

Smaller items (metal brackets, window frames etc.), normally classed as 'extraneous steelwork', would not normally be bonded as they are unlikely to adopt a potential, but it is usual practice to bond larger items such as staircases, ladders, cable trays etc. in substation areas, unless specified by the design engineer for stray current / segregation reasons.

Care should be taken at Hot sites if any LV equipment is mounted on HV-earthed steelwork. Bonding conductors (or armoured cable sheaths etc.) should not inadvertently combine the two systems. LV Sheaths should be held well clear of HV steelwork using plastic/non-conductive clips/clamps or similar.

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

11.2.1 Doors

Bonding of steel access doors (that may be touched from outside the substation) needs to be carefully considered: there are pros and cons to bonding; normally there is a trade-off between risk outside the substation (to members of public) and inside the substation (to operational staff). Electricity North West's preference is to keep steel substation doors 'floating', i.e. not bonded to HV steelwork, and insulated from ground. Such doors are increasingly used in GRP enclosures. It is however acceptable to bond these doors to HV steelwork on a Cold site, but if they are to be bonded on a Hot site, additional measures (as below) are required to minimise risk to members of public outside the substation. Due to the possibility that such measures may be overlooked or incorrectly installed, the 'unbonded' solution, in general provides reduced risk and is acceptable for normal doors up to 2m wide x 2.4m high.

Additional measures required for bonded doors (to enhance safety outside the substation) include:

- A loop of 70mm^2 bare copper cable or 25mm x 3mm bare copper tape shall be installed directly under the door at a depth of 300mm to 500mm. If practicable it should be outside the door, 1m from the door front and 500mm beyond each door frame. Each end of the loop shall be connected to the existing HV electrode using bare copper conductor. The complete loop shall be covered with a 100mm thickness of concrete to provide protection against damage or theft.

- Alternatively, a steel or copper mesh may be installed in concrete at a depth of 200mm to 300mm, covering the same area as above.

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

- The door framework shall be bonded to the HV earth using 35mm^2 aluminium or 16mm^2 copper covered stranded cable.

NOTE: The 'grading electrode' outside the substation doors provides additional protection to members of the public but may be omitted if the following criteria are all satisfied:

- The substation is designed with combined HV/LV earth.

- The substation is classified as a Cold site.

- The area outside the substation doors is either concrete or tarmac.

11.2.2 Metallic Fences

This applies to open compound sites only; fences around GRP enclosures do not require any special consideration.

The general rule for metallic substation fences is that, at Cold sites, they shall be bonded to the HV earth at all times.

NOTE: If the segregation distances below (for Hot sites) can be satisfied, the fence/gate/door may also be unbounded.

At Hot sites, bonded fences, gates and doors can be a shock risk to those outside the substation, and unbonded fences can be a risk to those inside the substation. Consequently, the fence at any Hot site SHALL NOT BE BONDED provided that:

- The fence is, in its entirety, situated more than 2m from any item of equipment or other earthed metalwork bonded to the HV earth, or

- A barrier exists sufficient to prevent simultaneous contact between the fence/gate/door and the other earthed metalwork.

If these conditions are satisfied, the fence cannot be touched at the same time as any HV earthed metalwork and the risk inside the substation is reduced. The fence (being unbonded) will not rise to the full EPR under earth fault conditions and the risk outside the substation is managed.

For any separately earthed fence (unbonded fence), a nominal electrode is required to discharge any small charge that might otherwise build up due to electromagnetic effects, as described in ENA TS 41-24. Typically for small sites this will consist of corner electrodes inside the fence line. If any overhead line crosses the substation, the fence must have its own electrode system capable of quickly operating HV protection should the line fall, and electrodes shall be installed 1m either side of the line crossing for this purpose (unless corner electrodes are already at these locations). These electrodes, and any fence foundations, should be well clear of buried HV cables, and metallic sheathed cables (if any) shall be insulated (ducted) over a 2m length where they pass under the fence line.

If simultaneous hand-to-hand contact between the unbonded fence and HV steelwork cannot be prevented by barriers/insulation/separation, it may be bonded only if the risk outside the substation can be managed by use of grading electrodes and appropriate ground coverings such as chippings or tarmac. Alternatively the fence could be replaced with a non-metallic one.

Note: Due to the small size of most secondary substations, metallic fences and gates will nearly always be within 2m of the equipment and bonding to HV may seem appropriate in most cases. Additional measures will be required to prevent danger to those outside the substation; if these measures are not practicable, barriers may be used inside the substation to prevent hand-to-hand contact between a separately earthed fence and HV equipment. Alternative measures (such as the use of insulating paint) may be discussed with Electricity North West.

Electricity North West will need to see computer modelling or calculations to confirm that touch voltage on any bonded fence is acceptable. Risk assessment (for issues outside the substation) may be appropriate in some circumstances; consult Electricity North West for further details.

Where a grading electrode is required (e.g. Hot site with bonded fence):

- A grading electrode of 70mm^2 bare copper cable or 25mm x 4mm bare copper tape shall be installed under the fence line, or just inside (or outside), ideally at a depth of 500mm (300mm minimum) and connected to the fence; this is to protect staff and the public from dangerous touch voltages. Ideally, and if practicable, the grading electrode should be installed outside the fence at a distance of 300-500mm away from the fence (in some situations the designer will specify an outside grading electrode, in which case an electrode underneath or inside the fence line is unacceptable).

For all metallic fences:

- Each metallic gate shall be bonded to the gatepost using flexible 35mm^2 covered stranded aluminium cable or 16mm^2 covered stranded copper cable or tinned copper braid.

- Each pair of gateposts shall be bonded together using flexible 35mm^2 covered stranded aluminium or 16mm^2 covered flexible stranded copper cable (unless the frame is a single piece ‘goalpost’ type arrangement).

Fence earthing can be problematic, although these problems are usually apparent at larger sites or where different earthing systems exist. Problems have arisen in the past due to fences providing inadvertent connection between Electricity North West's HV earth and e.g. a railway or pipeline operator's earth, or due to the possibility of exporting dangerous potentials to a third party fence etc. (where a hazard could exist further along the fence line). To address these concerns, insulated fence panels or stand-off insulators can be used with care:

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

NOTES

1. Such measures (insulated panels etc.) are less likely to be required at Cold sites or on small unbonded fences, but may be required to protect Electricity North West's system from some third party installations (e.g. if diverted AC or DC current flows could flow). The advice of an earthing specialist should be sought if a substation's proximity to other systems could foreseeably give rise to danger or damage to either system.

2. In general where the substation fence is bonded to the HV earth no other metallic fencing or conducting material shall be abutted to the fence or within 2 metres of it. Metallic third party fences should not be within simultaneous touching distance (2m) of metalwork/fences connected to the HV earth. If necessary measures such as outlined above should be introduced outside the substation boundary. If this is not practicable then specialist advice should be sought.

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

11.2.3 Ancillary Metalwork

At Cold sites, all other exposed and normally un-energised metalwork inside the substation perimeter (e.g. ventilation ducts, staircases etc.) within 2m of other earthed metalwork shall be bonded to the main earth using 16mm^2 covered copper cable or equivalent to avoid any voltage differences between different items of metalwork[3].

At Hot sites, all such metalwork shall be bonded in the same way, except if the metalwork might give rise to risk outside the substation, in which case the advice of Electricity North West's expert shall be sought. Often the decision on whether to bond, or otherwise, needs to be backed up by appropriate risk assessment.

NOTE: Metal frames and other metallic parts that form part of a GRP enclosure may be excluded.

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

11.3 Pipework and other Metalwork including Telephone System Cabling

Any substation (and its associated earthing system) in non GES areas shall be segregated from all metal pipework above or below ground by a minimum of 2 metres.

The requirement for separation is most important when the substation is Hot, as the third party operating the equipment will need to know the extent of the Hot-Zone and will endeavour to route their equipment outside the relevant voltage contour. If the equipment is pre-existing, a risk assessment or other measures may be necessary if Electricity North West's equipment cannot realistically be installed elsewhere. In some cases it may be necessary to make the site Cold if this is a practicable solution.

Some pipeline operators in UK (e.g. the Government Pressurised Storage System (GPSS)) will insist that all Electricity North West substations are 50m from their pipelines (this being a figure quoted in various oil/gas standards). If this distance cannot be achieved, the designer must undertake detailed studies to confirm that there will be no significant risk to the pipeline operator or their staff, to the satisfaction of the pipeline operator. If in doubt, consult Electricity North West's earthing specialist.

11.4 Combined HV/LV Earths

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

11.5 Separate HV/LV Earths Additional Requirements

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

Extra care is required to ensure that:

- The HV to LV link is removed from the LV cabinet.
- All earthed metalwork is more than 2m from any other metalwork.
- Separate HV and LV earths are not inadvertently combined.
- Additional PME earth electrodes are installed outside the 430V zone.
- All properties with LV supplies are outside the 430V zone (or subject to an appropriate risk assessment).

11.5.1 LV Earth

A separated LV earth electrode shall be:

- Selected to provide a resistance of 20Ω or less.
- Separated from any HV electrode by a sufficient distance to ensure the LV earth is located outside the 430V contour. Further guidance in CP333.
- Installed under an LV main cable in the cable trench wherever practicable to enhance its security.
- Connected to the **neutral bar** in the LV pillar/cabinet using 70mm^2 covered copper conductor (and laid under the LV cable).

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

11.5.2 Warning Notices for Separated Earths

Where the HV and LV earths are separated, warning labels shall be installed next to the neutral-earth connection and on the site as required by Electricity North West.

11.5.3 Lighting and Socket Supplies

Care shall also be taken with lighting and socket supplies to avoid operator contact between different earthing systems. Therefore at Hot sites:

- Light switches and conduits shall be plastic; metallic light switches, socket outlets and conduits **shall not be installed within** 2m of any metalwork bonded to the HV earth.
- All 13A sockets **shall be disconnected or removed** from LV fuse cabinets and LV pillars.
- Alternatively LV and RTU supplies shall be provided via an isolation transformer with a 5kV insulation rating.

11.5.4 Street Lighting Columns

New substations with separate HV and LV earths shall not be installed within 2m of street lighting columns or other street furniture.

However where this is impractical the columns shall be earthed via a separate earth rod installed adjacent to the column and shall **not** use the neutral/earth of a PME service. This will usually necessitate the use of an RCD in the columns/furniture to ensure adequate disconnection time for LV faults. It may be preferable to relocate the LV equipment or to use non-metallic substation doors.

11.6 Cables

All HV cable earth screens shall be bonded to the transformer or switchgear earth terminal. Cable screens are vital to ensuring the safety of ground mounted plant and three-core or triplex screens should be made off separately, rather than bunched into a single lug/connector, where possible to provide increased resilience.

All LV cables shall be bonded as follows:

- **Combined Neutral Earth (CNE) cables** - the outer sheath of the cable shall be connected to the neutral bar in the LV pillar/cabinet.
- **Separate Neutral Earth (SNE) cables** - the outer sheath and armouring shall be bonded together and connected to the neutral bar in the LV pillar/cabinet/board. The neutral conductor shall be connected to the neutral bar in the LV pillar/cabinet/board.

11.7 Post-Installation Testing

The substation earthing system shall be tested after installation (but before connection to HV or LV networks where possible) and a report produced to satisfy Section 10.3 of this Specification.

12. ADDITIONAL INFORMATION / SPECIAL CASES

12.1 Building Façade with Metallic Cladding or Panels

Building cladding can introduce risks due to either:

1) Exporting an EPR from substation to larger area where public may be present, or

2) Providing a different earth system that could cause a hand-to-hand shock risk if it can be touched at the same time as the substation HV (or LV) systems.

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

The easiest and best course of action for Cold sites is to bond the building steelwork (including the metal façade) to the HV/LV system in the normal way. The building foundations and lightning system (if any) will serve to fortuitously reduce touch voltages and in most cases it will be shown that an 'F factor' of 2 (refer to BS EN 50522) applies in which case a touch voltage of 466V (on soil or wet concrete) is acceptable. Asphalt around the building gives a greater margin of safety.

In such cases it is arguable that the LV risk (resulting from a broken neutral) is greater than that resulting from a HV fault. The risk of broken neutral should be minimised in the normal way, by using duplicate and robust connections wherever possible.

12.2 Customer HV Supplies and Associated Substations

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

NOTE: Electricity North West is not responsible for a HV customer's LV earthing arrangements but has a duty of care to ensure that the customer's LV system will not become dangerous in the event of a HV fault.

The customer shall provide an HV earthing system for their installation that is adequate to ensure safety of (and around) their installation, irrespective of the earthing provided by Electricity North West. The earthing system should normally consist of copper earth electrodes (tapes and rods) and steel reinforcement piles or rebar in the vicinity of the substation. In the majority of cases the earthing systems can be interconnected, especially when the resulting earth resistance is low enough to achieve an EPR below 430V. In this case it may also be possible to use the same earthing system to provide the LV earth. This is illustrated in Fig. 2. The aim of the design is to ensure that Electricity North West and customer earthing systems shall each be adequate to ensure safety in the absence of the other system. The customer system shall not be reliant on Electricity North West's earth terminal for safety (and vice-versa) since the integrity of either system can be subject to external influences.

In some situations, it may be necessary to rely on combined systems to ensure safety of both systems (i.e. where safety of each system in isolation cannot economically and/or practically be achieved). In such cases, the systems shall be combined with duplicate connections, and the customer system shall be constructed to Electricity North West's standards (in terms of conductor sizing, method of installation and touch/step considerations). However, care is needed if the customer system should become decommissioned or compromised; clear labelling and test facilities will enable Electricity North West to assess whether any customer contribution has been lost.

The situation is more complex if the EPR exceeds 430V the following design options shall be considered:

- Extend the HV earth or reduce the earth fault current to reduce the EPR below 430V, if this is possible at a reasonable cost. One option for substations on new networks close to existing urban/suburban networks is to interconnect the earthing with existing HV sites that have metallic sheathed cables or connect onto abandoned sheathed cables. Or:

- Interconnect the HV and LV earths and operate with the necessary measures in place. This is only really practical at an isolated location such as a 'standalone' factory or office, a wind or solar farm, generating station or National Grid site. Consult with Electricity North West's earthing expert if this is likely to provide a workable solution. Or:

- Separate the HV and LV earthing systems sufficiently to prevent the EPR on the LV earth system rising above 430V. This will generally require modelling. Ensure that they cannot be interconnected. Precautions will also be required to ensure that a person cannot contact both earth systems simultaneously.

- Segregate the Electricity North West HV earth from both of the customer earths. This is difficult to achieve, is not a desirable solution and generally requires a special design. Options to achieve it include introduction of a span of unearthed overhead line or cable sheath insulation joints between the site and the Electricity North West system (e.g. similar to that outlined in ENA EREC G78 for mobile phone masts). However, the working practices (such as isolation and earthing for work on the HV system) need careful consideration in this situation.

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

12.3 Customer Generation

The earthing system for a secondary substation for an HV generator connection shall be designed in accordance with CP333, as described in this Specification. The earthing system associated with the generator shall in general be designed in accordance with industry and national standards, however if the generator earthing system forms an integral part of the Electricity North West substation earthing system it shall also be designed in accordance with Electricity North West standards. Further guidance for solar and wind farm is given below.

12.4 Solar Farms

Electricity North West 11kV connections to solar farms normally terminate at a metering unit installed on customer land. This metering unit will be designed to normal Electricity North West standards and must be safe without reliance on the solar farm contribution.

Solar farm switchgear etc. will then be connected to this metering unit, and (in most cases) the solar farm earth connected to the Electricity North West earth via the cable sheath and duplicate 70mm^2 stranded or 25x3 copper conductors. The solar farm system should be safe for normal ground return current (as used for the Electricity North West substation design), but without considering any 'network contribution' from Electricity North West's network. In most cases, solar farms have a ring of copper electrode encompassing the whole site, and this provides a sufficiently low resistance to limit EPR and produce acceptable touch/step voltages.

The Electricity North West and solar farm earthing systems will then normally be combined and run as a single earthing system; if a Cold site cannot be achieved when combined, appropriate precautions shall be taken (such as a separately earthed fence) to control touch voltages inside and outside the site in the normal way.

In some situations (such as when connected via Overhead Line and with little or no network) it may be difficult for Electricity North West to achieve a safe substation without reliance on the solar farm earthing system. If the Electricity North West system serves only to provide the solar farm it is reasonable to include the solar farm electrode in the design calculations for the Electricity North West metering substation. In this case the solar farm electrode must be designed to Electricity North West standards (i.e. 70mm^2 copper conductor with minimum strand diameter 2mm, or copper tape) and facilities in place for its contribution to be measured periodically using a clamp meter.

Galvanised wire electrodes or ultra flexible / tri-rated copper conductor (thin strands) shall not be used as electrode.

In some rare situations it may be necessary to operate with the solar farm earthing system segregated from Electricity North West earthing system, normally if one part of the site is Hot or if there is a transfer potential issue from e.g. National Grid Tower in close proximity to the solar farm. This is beyond the scope of this document and in these conditions the advice of Electricity North West's earthing expert should be sought.

12.5 Wind Farms

Similar to solar farms above. Each turbine typically will have a foundation electrode and grading ring(s). Turbines may be daisy chained together using bare copper electrode, or using HV cable sheaths. The combined resultant earthing system may be included in calculations for Electricity North West substation if it is not practicable to achieve a safe site otherwise.

12.6 Supplies to Hot Sites such as National Grid Substations or Towers

Care is required so that existing Hot sites do not export dangerous potentials along HV cable sheaths and ultimately to Electricity North West customers and staff. Special measures such as sheath breaks, overhead line sections, or isolation units may be required to keep earthing systems separate. Refer to CP333 Appendix C and (for Towers) ENA EREC G78. Further guidance may be found in Electricity North West's CP215.

12.7 Secondary Substations in High-Risk Locations

Where possible secondary substations shall not be installed near to high-risk areas including:

- Areas where the public may normally be bare footed, e.g. outdoor swimming pools, showers, nudist colonies etc.

- Areas often frequented by horses or livestock, e.g. next to a stable, in zoos, etc.
- Areas containing sensitive electronic equipment, e.g. telephone exchanges, air-traffic control equipment, radar stations, etc.
- Within 20m of a fuel filling station.
- Within 50m of a buried gas or oil pipeline (see below).

If this is unavoidable a detailed design assessment shall be undertaken by a specialist to optimise the location of the substation electrodes to control the risk.

12.8 Secondary Substations near Railways / Tramways

Secondary substations located near to, or providing supplies to, railway infrastructure (especially AC or DC electrified systems) shall be referred to a suitably qualified person who will assess the additional risks and liaise with the railway infrastructure owner as necessary. BS EN 50122 provides some additional information. Also refer to ENA ER P24 and Electricity North West CP332 (Customer Earthing and Application of PME).

It may be necessary to control risks associated with transfer potential from a Hot site (the Electricity North West or Traction Substation could be Hot).

On DC electrified railways / tramways there are additional risks of corrosion of Earth Electrodes via passage of stray current that also need to be managed via design. Electricity North West electrodes and cables should remain at least 10m away from underground structures bonded to these systems, where possible, and should be regularly tested/inspected to ensure they are not subject to accelerated corrosion.

Any design decisions taken should be discussed with Electricity North West and suitably documented.

12.9 Secondary Substations near Pipelines

Where practicable, secondary substations (and their Earth Electrodes) should not be installed within 50m of a pipeline. Where this is unavoidable an earthing specialist or suitably qualified person should be consulted who must 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. The assessment should follow the approach set out in BS EN 50443 and will involve calculation of potential gradients around and longitudinal current in the pipeline.

12.10 Lightning Protection Systems

Lightning protection is covered by BS EN 62305 (protection against lightning). BS EN 62305-3 specifies that the resistance of the lightning protection system (LPS) should not exceed 10Ω and that it is preferable to have a single integrated earthing system. Further guidance is given in CP314.

An Electricity North West or customer lightning protection system on or near to a secondary substation shall be connected to the substation HV Earthing System providing that:

- The lightning protection system has an independent Earth resistance of 10Ω or lower (before connection to the Electricity North West Earthing System).

- The substation is a Cold site.

If the above statements are not satisfied guidance should be sought from Electricity North West.

The connection point should be clearly labelled, and bolted to facilitate disconnection under controlled conditions should this be necessary on rare occasions. Removable links are permissible for this main link but generally discouraged due to safety risks associated with making/breaking connections.

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

If a removable link is provided a warning label shall be installed close to the link.

NOTES:

There will be an electric shock risk between the two earthing systems when the link is removed

If the two earthing systems are not bonded then care is required (even at Cold sites) to ensure that metalwork connected to the two earthing systems cannot be touched simultaneously.

If the two earthing systems are not bonded then during lightning strike conditions a flashover may occur between the lightning conductors and any pipework or conductor (including cables within the customer's installation) connected to the earth terminal.

12.11 Secondary Substations within Grid or Primary Substations

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

Secondary substations at Hot primary or grid sites shall not feed out to LV networks. Similarly LV networks must not feed into Hot substations without special measures to ensure safety.

12.12 Substations Located near Cathodic Protection Systems

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

Electricity North West's substations or other metallic plant close to this current flow path can provide a parallel (low impedance) path for DC currents. Such stray currents, where they exit the Electricity North West system, will cause erosion of metalwork.

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

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

13. DOCUMENTS REFERENCED

Electricity Safety, Quality and Continuity Regulations.

BS EN 50522	Earthing of power installations exceeding 1 kV a.c.
BS 951	Electrical earthing. Clamps for earthing and bonding. Specification.
BS 7430	Code of practice for protective earthing of electrical installations.
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 ER G12	Requirements for the Application of Protective Multiple Earthing to Low Voltage Networks.
ENA ER G78	Recommendations for low voltage connections to mobile phone base stations with antennae on High Voltage structures.
ENA ER P24	AC traction supplies to British Rail
ENA EREC S34	A Guide for Assessing the Rise of Earth Potential at Electrical Installations.
EPD333	Supply System Earthing.
CP215	Supplies to Mobile Phone Base Stations with Antennae on High Voltage Structures.
CP314	Lightning Protection of High Voltage Overhead Line Systems.
CP332	LV Service Connections & Application of PME.
CP333	Earthing Design for 11/6.6kV Distribution Substations and Equipment.
CP335	Earthing Design for 33kV & 132kV Grid and Primary Substations and Equipment.
CP411LV	Mains Practice up to and including 132kV. Cable Jointing up and including 1000 Volts.

14. KEYWORDS

Earthing; ICP; IDNO; Substation