Code of Practice 333

Issue 9 Sept 2023

Earthing Design for 11/6.6kV Distribution Substations and Equipment

Amendment Summary

ISSUE NO. DATE	DESCRIPTION
Issue 7 **June 2021**	Standard design for HV earth mat installations can be used where the installation has no LV earth mat – line switches, ABSDs, Sentinel equipment. This greatly simplifies the design process for these types of installations. References to the standard arrangements in CP430 and CP420 added. References to design aspects for overhead line systems in CP411 have been removed. Design policy currently in CP411 makes reference to the obsolete 1Ω rule and is being removed. Prepared by: Peter Twomey Approved by: Policy Approval Panel and signed on its behalf by Steve Cox, Engineering and Technical Director
Issue 8 **June 2022**	Addition in Section 7.2 of reference to Standard Technique 63 in CP411Pt2N for procedure for using decommissioned lead sheath cables as horizontal earth electrode Prepared by: Philip Howell Approved by: Policy Approval Panel and signed on its behalf by Steve Cox, DSO Director
Sept 2023	Contents of EPD333 Supply System Earthing added. EPD333 withdrawn from library. Prepared by: Peter Twomey Approved by: Policy Approval Panel and signed on its behalf by Paul Turner, PAP Chair

Contents

1 Introduction

1.1 General

Part 1 of this document "Supply System Earthing" defines the policies adopted within Electricity North West Limited (hereinafter referred to as Electricity North West or ENWL).

Part 2 provides a means of complying with EPD333 for 11/6.6kV distribution substation earthing design. The earthing design for 33kV & 132kV substations and equipment is covered in CP335.

11/6.6kV distribution substation earthing arrangements are now standardised for a variety of layouts/substation types; these are described in Section 6 and Appendix A. 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. 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.

Where standard layouts are not adequate, refer to Section 5.4.3 ('Type 3 – Detailed Assessment'), and to the general design principles given in CP335.

Where the reader is invited to seek specialist advice, this shall be sought via Electricity North West's suitably qualified staff.

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, 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.

1.2 Foreword to Issue 4

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 (Guidelines for the design, installation, testing and maintenance of Main Earthing Systems in substations) 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 principles are applied, together with Electricity North West's operational experience and local practices, to designs and methodologies described in this document.

Compliance with this code of practice will meet EPD333 requirements for all 11/6.6kV distribution substations.

2 Scope

Part 1 This EPD defines the policy to be applied to the earthing arrangements for Electricity North West Limited' system operating over the voltage range LV to 132kV.

This policy applies to all new earthing installations on Electricity North West Limited distribution system. The policy is not intended to be retrospective; but where work is being done on the system, the opportunity should be taken to make modifications that will apply this policy to existing arrangements, where such work can reasonably be accommodated within the scope of the project.

Part 2 of this document sets out the requirements for the design and construction of the Earthing Systems for 11/6.6kV distribution substations, detailing Electricity North West's preferred Earthing System designs, and establishing base parameters for determination of the earthing design to be implemented at a specific site. Compliance with this code of practice will ensure that a safe and efficient Earthing System is implemented at each site.

The following situations are outside the scope of this document:

- Customer private HV earthing arrangements.
- Supplies to Mobile Phone Base Stations (refer to CP215).
- LV supply arrangements.
- Primary or Grid substation earthing (refer to CP335).
- Supplies to all railway/traction/auxiliary sites (Refer to CP332 and P24).

Part 1 – Supply System Earthing Policy

3 Neutral Earthing

The 132kV system shall be operated with the neutrals of all 132kV transformer windings directly connected to earth.

The 33kV system shall normally be earthed at the Electricity North West Limited owned bulk supply transformers only. Each bulk supply transformer shall be resistance earthed to a value of 1000 ampere per transformer using earthing resistors to Engineering Specification 350 of nominal value 19.05 ohm at 15°C. If earthing transformers are used to provide a neutral, these shall be in accordance with Engineering Specification 324.

The 11 and 6.6kV systems shall normally be earthed at the Electricity North West Limited owned primary substation supply transformers only. Each primary supply transformer shall be resistance earthed to a value of 1000 ampere per transformer using neutral earthing resistors to Engineering Specification 350 of nominal value 6.35 ohm for 11kV and 3.81 ohm for 6.6kV at 15°C. For the case of systems supplied from 11kV delta windings of 132kV transformers, there shall be provided earthing transformers to Engineering Specification 324.

The LV system shall be operated with solidly earthed neutrals. Neutrals of adjacent systems shall be interconnected subject to the requirements of the Electricity Safety, Quality and Continuity Regulations 2002.

Any proposal to operate other than as described above shall be referred to the Head of Safety and Policy for consideration.

4 Design Standards

Distribution substations operating with maximum voltages of 11 and 6.6kV shall have their earthing systems designed in accordance with the requirements of the Electricity Safety, Quality and Continuity Regulations 2002, EATS 41-24 and BS EN 50522. In all cases, provision shall be made to individually test the continuity and resistance of each earthing system component.

To achieve this within Electricity North West Limited, an earthing system (as appropriate) described in Electricity North West Limited CP 333 "Earthing Design for High Voltage Substations and Equipment" shall be installed.

The maximum earth resistance for electrode systems on an 11kV system is 40 ohm, and on a 6.6kV system, 25 ohm. This will ensure reliable operation of earth fault protection at these voltages.

All substations operating with maximum voltages exceeding 11kV shall have an earthing system designed in general accordance with EATS 41-24. Within Electricity North West Limited, staff may ensure compliance with these requirements by use of:

(a) reference to CP335 Earthing Design for Grid and Primary Substations

(b) reference to Electricity North West Limited Code of Practice 333 "Earthing Design for High Voltage Substations and Equipment"

5 Network Connection to Earth

The Electricity Safety, Quality and Continuity Regulations 2002 require network operators ensure, as far as reasonably practicable, their networks remain connected to earth for all foreseeable operating conditions. The neutral earthing arrangements of primary and grid transformers make it possible to have unearthed network on the high voltage side of the transformer when fed from the low voltage side, if the high voltage network becomes islanded. So far as reasonably practicable, no new connection or modification to the network shall create situations where unearthed network is possible, without the installation of auto tripping scheme to automatically disconnect the unearthed network following a protection operation during the normal running arrangement.

Existing situations where unearthed network can be created during abnormal network running arrangements shall be considered for mitigation. Where pilot cables are required and are available, cross tripping schemes shall be installed to automatically disconnect network in order to avoid it remaining unearthed.

Part 2 – Earthing Design for 6.6kV and 11kV networks

6 Definitions

Backup Protection	Protection set to operate following failure or slow operation of primary protection – also see Normal Protection. For design purposes, the Backup Protection clearance time may be taken as a fixed (worst-case) clearance time appropriate to the network operator's custom and practice.
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.
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".
Normal Protection Operation	Clearance of a fault under normal (usual) circumstances. The normal clearance time will include relay operating time and mechanical circuit breaker delays for all foreseeable faults and may be calculated for design purposes. Alternatively, a network operator may work to the worst-case protection clearance time applicable to the network in a given area. 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. NOTE: Certain parts of an earthing design should consider slower Backup Protection operation which allows for a failure of normal protection. See 5.4.3.3 Additional Rule 1.
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.

7 Risk Assessments

The following areas of work associated with this code of practice require special consideration and attention to detail in order to avoid the risks identified herein.

7.1 Driving of Earth Rods

All practical steps shall be taken to ensure that rods are not driven into any buried services such as gas, telephone, water or electricity mains. Reference to the appropriate utilities records and the use of approved instruments for the detection of buried services may be necessary. Refer to CP411 Pt1 N.

7.2 Bonding and Connections between Metalwork

All normally accessible metalwork, such as the transformer tank, LV pillar enclosure, metal fencing, metal tapes in non-metallic casing etc. shall be connected together and to the HV Earth, via Bonding Conductors. All conductors used for bonding and connection shall be of no smaller a cross sectional area than specified in Appendix B. Only copper conductors shall be buried, and special attention must be given to forming good joints having anti-corrosive performance (Section 7). Failure to observe these requirements could result in persons being exposed to a danger of bridging across unbonded metalwork, with a possible potential difference between such metalworks causing a risk of electric shock.

Fence bonding can be problematic, in that some installations are specifically designed to have a bonded metal fence (i.e. connected to the substation HV Earthing System), whereas others are designed for the fence to be separately earthed (by means of its own rods etc.). Care should be taken to ensure that separately earthed systems are not inadvertently bonded together, and to ensure that simultaneous (e.g. hand-to-hand) contact between the systems cannot occur. Additional requirements exist on Hot sites, as detailed in CP278, where segregated Earthing Systems are commonplace.

7.3 Touch and Step Potentials

'Touch potential' describes a hand-to-feet (or sometimes hand-to-hand) shock voltage that can appear on metalwork under fault conditions. Electricity North West's standard designs (Appendix A) reduce voltage differences (and thus shock risk) by careful use of equipotential bonding and potential grading (electrode placement). The standard designs may be augmented (added to) in some circumstances but must not otherwise be modified without authority of the design engineer.

Having chosen a standard layout, the designer must ensure that touch voltages do not exceed the permissible limits given in ENA TS 41-24 (reproduced in Appendix B). The procedure outlined in Section 5.4 should be followed.

Electrode shall not be positioned where it can cause a hazard e.g. touch/step voltages (to humans) or, in the case of Hot substations, must not be closer to any LV system or LV electrodes than calculated minimum clearances (refer to Appendix B).

Any risk from buried electrodes tends to reduce as the physical size of an electrode system increases. In particular the electrodes on overhead systems are often of relatively small dimensions and high resistance, factors that contribute to the risks. The required physical size for an electrode system is detailed in Section 5.1.4 and must not be reduced.

7.4 Measurement of Earth Resistance

The usual method of measuring Earth resistance is by use of instruments requiring connections to remote, temporary Earth spikes. There is, as a general rule, always some risk of potential difference existing across remote positions in the ground. The manufacturers' instructions for the use of the instruments must be followed to avoid danger. The use of dielectric boots and/or insulating gloves is necessary whenever handling conductors connected to remote ground points. Refer also to Appendix D, and to CP411 Pt1 N Standard Technique 10.

8 Earthing Design Approach

8.1 General

The approach for ground mounted substations has changed, in that (in many cases) a standard resistance value is no longer appropriate. For these, **the designer must instead calculate a Target Resistance value** (except for type 1) and confirm that the resulting safety voltages (touch, step, and transfer voltages) are acceptable.

Electricity North West substations fall into three categories as described in Table 1. The majority of sites will be 'Type 1' requiring little or no calculation effort.

Table 1: 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 300Ω.m or better .... Impedance earthed source substation (max. 2kA Earth Fault Current). .... Cold source substation with resistance < 0.17Ω (or measured Network Contribution < 0.17Ω)‡ .... Standard Electricity North West substations without metal fences / enclosures, in GRP or integral substations with Touch% <=10%................................	 ☑ ☑ ☑ ☑ ☑ ☑ ☑

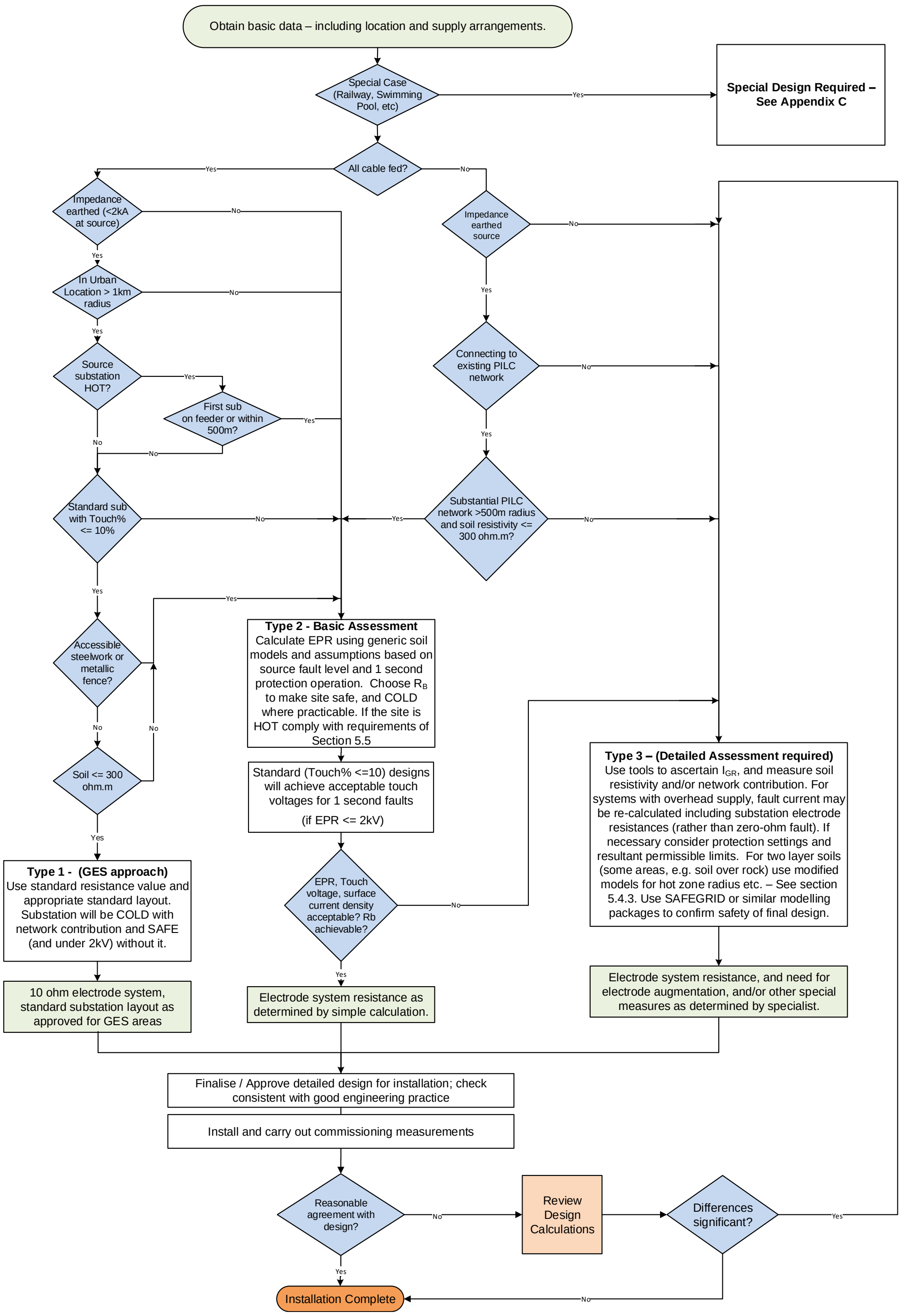
	These sites do not require detailed assessment. See Section 5.4.1.
Type 2 (Basic Assessment)	Anything that fails the tests for Type 1 above (i.e. any un-ticked boxes). These sites require a basic assessment (Section 5.4.2). Except, if the basic assessment reveals an EPR* > 2kV or the site is HOT, when the requirements of Type 3 assessments must be.
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 (>300Ω.m) / Rock / difficult ground conditions / Little or no nearby network / Nonstandard substation / Metal fences or pad-mount.
* EPR – Earth Potential Rise ‡ This requirement is assumed to be satisfied if the 'network area' and 'soil resistivity' boxes are ticked	

In general, for Type 1 substations a detailed earthing design is not necessary. It is expected 75% of Electricity North West substations will fall into this category.

In all other cases it will be necessary for the designer to calculate EPR and touch voltages.

The outline procedure is given in the flowchart below.

Fig. 1 – Design Flowchart



Appendix D gives some worked examples.

8.1.1 Ground Mounted Substations – Features

All installations (irrespective of 'Type 1'/GES status or otherwise) shall utilise one of Electricity North West's standard designs as detailed in Appendix A. These designs have been modelled using computer software to establish their resistance to Earth in a given soil resistivity, and the touch voltage as a % of overall Earth Potential Rise (EPR).

All Electricity North West standard designs utilise a perimeter electrode (or 'grading electrode'), this is designed to modify the voltage appearing on the ground surrounding the substation. It plays a significant role in limiting Touch Potential / shock risk and MUST NOT be omitted or modified.

The designer must ascertain the Earth resistance required to make the site SAFE and/or Cold if appropriate, using the rules in Section 5.2 For Type 1 (GES) sites, no calculation is required provided a standard layout with Touch% <= 10% is used. However, other sites will require additional consideration.

8.1.2 Pole Mounted Substations / Switchgear

Arrangements for Pole Mounted Transformers (PMTs) are largely unchanged from previous versions of this standard.

The earthing arrangements covered in CP420 part 1 Chapter 21 shall be the preferred design for Electricity North West's 11/6.6kV pole mounted distribution transformers and equipment.

Pole mounted steelwork can rise to dangerously High Voltages under fault conditions, and safety is managed by

- Placing out of reach, and
- Ensuring adequate separation / isolation from the LV network, so as not to cause a hazard due to potential transferred to LV under HV fault conditions.

Pole Mounted equipment can approach (or sometimes exceed) 6kV during HV Earth Faults, and therefore the transformer specification shall be such that flashover (to the LV) will not occur. If surge arrestors are installed across the LV neutral bushing they should be removed, or rated >10kV, since a hazard can be introduced on the LV network (and in customer's premises) if the surge arrestor begins to conduct. It is generally accepted that EPR on pole mounted systems may be present for up to 3 seconds.

If any pole mounted system is moved to ground level (e.g. replaced with pad-mount transformer or similar), the earthing arrangement MUST be suitably designed for this application. It is **not permissible** to simply re-use the existing HV electrode since this will not be adequate to safely control Touch Potentials on the new transformer. The 'Type 2' assessment of Section 5.4.2 should be carried out as a minimum.

8.1.3 Conductor Sizes

All Electricity North West standard arrangements use buried bare copper conductor to act as both a means of connection (e.g. between buried rods) and to function as an Earth Electrode. The minimum cross sectional area of buried copper conductor within the confines of a substation Earth loop shall be 70mm^2 unless otherwise stated. Refer also to Appendix B.

8.1.4 Surface Current Density Requirements

Sufficient electrode must be installed to prevent drying of the soil and/or steam formation at its surface under fault conditions. The electrode installed to achieve the required earth resistance of 10Ω will normally be adequate in most cases, but detailed calculations may be required in some situations.

Studies have shown that Type1 standard designs in a Global Earthing System will meet surface current density requirements and no further assessment is required. For Type 2 or 3 designs a site-specific calculation will normally be carried out and may indicate the need for additional electrode to be included in the design.

For calculations (described in detail in ENA EREC S34), the normal ground-return current I_{GR} (i.e. not earth-fault current) should be considered, together with a clearance time of 3 seconds to ensure the system remains intact for backup protection operation. The requirement should be ideally met by the copper electrode system in isolation, but the foundation rebar may also be included (where a disproportionate amount of additional copper electrode is required to meet this requirement) if it is effectively connected to the earthing system.

8.1.5 Target Resistance

In all cases, after construction, the overall resistance to Earth of the Earthing System shall be measured and recorded **before connection to the HV or LV network**. It must be equal to, or less than the 'Target Resistance' specified by the designer in the Rules below. Measurement methods are described in Appendix D.

8.2 Rules for Ground Mounted Substations

(a) The substation shall be SAFE (in terms of touch voltage).

NOTE:

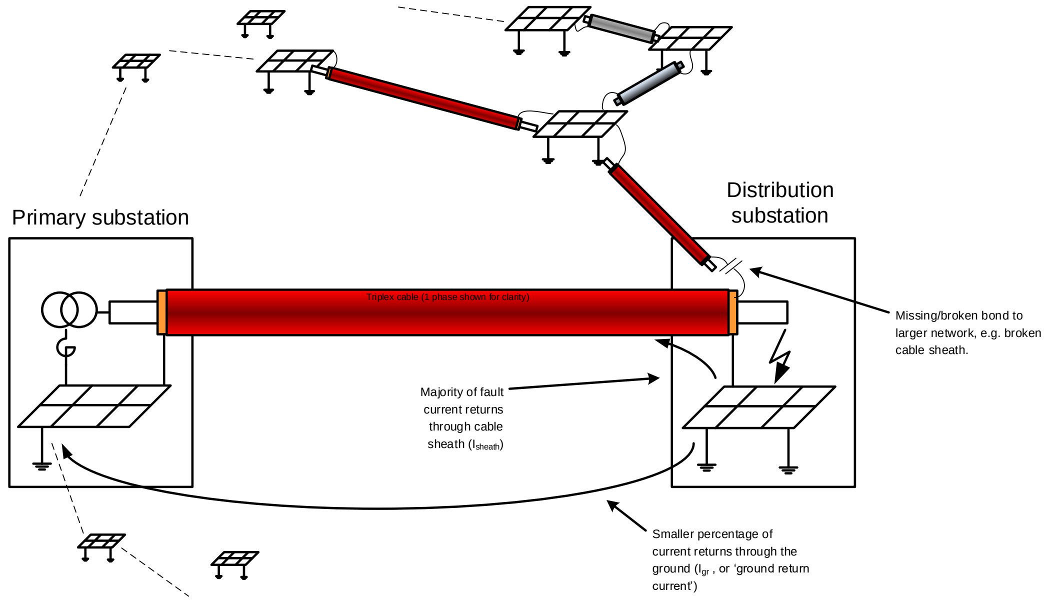
Where applicable, this calculation shall consider sheath return / Ground Return Current split, i.e. a normal reduction in Ground Return Current (I_{GR}) due to the sheath of the supplying cable but must not include the resistance of the wider area Network Contribution. Horizontal, buried conductor may be included in the calculation. The electrode effect of the supplying cable may also be included within the calculation.

Figure 2 shows continuity of the main (feeding) cable to a distribution substation, with a disconnected connection to the wider area network. In practice, complete loss of continuity to a surrounding network is unlikely, particularly on a Cold network, but represents not just a) disconnection / failure of said bond, but also b) future reduction in Network Contribution caused by development / alterations. This provides a factor of safety. For GES / Type 1 installations, the complete loss of continuity to surrounding network need not be considered.

Figure 2 applies to Rules 1 and 2 only. It does not apply to Rules 3 and 4 where wider Network Contribution may be included in the calculation of EPR.

For Type 2 or Type 3 installations, if a customer HV Earthing System is present and will be bonded to Electricity North West's system, the contribution of the customer's Earth should not be considered, i.e. should not be relied upon to ensure safety at the Electricity North West installation.

Fig. 2 – Contribution of Cable Network to Earth Impedance and Parallel Fault Current Path



(b) The resistance of the HV electrode system in isolation of the network shall not, exceed 10Ω unless special circumstances require.

NOTE:

The connection to the wider network (Network Contribution) shall not be considered for this calculation. Buried horizontal conductor may be included.

(c) The substation shall be designed to Cold where reasonably practicable, i.e. its EPR must not exceed 430V.

NOTE:

The connection to the wider network (Network Contribution) can be considered for this calculation. It may be assumed the network is intact.

It will often be possible to make a site Cold by installation of substantial electrode; however, the cost associated with this may not be justified. The designer may wish to consider local arrangements, for example if neighbouring substations are Hot then it may not be practical or necessary to establish a Cold site. Conversely, if all surrounding substations are Cold, then it will often not be possible to install a Hot site due to problems achieving segregation (for example, existing HV and LV cables may be metallic sheathed and in close proximity). In such circumstances, the designer may be left with little alternative but to achieve a Cold site.

(d) The EPR at a substation which is Hot must not exceed 3kV and must employ special measures (segregation) to ensure the LV system is protected from HV faults. The wider Network Contribution may be considered in this assessment. The main LV earth (electrode plus radials) shall not exceed 20Ω.

NOTE:

Some customer installations (e.g. HV metered customers) may be able to withstand higher EPR than 3kV. This is predominantly limited by insulation withstand of the transformer LV windings/bushings and associated wiring. Customers designing to higher EPRs will need to confirm in writing that their equipment, and installation as a whole, will be capable of operating safely at this level.

The connection to the wider network (Network Contribution) can be considered for this calculation. It may be assumed the network is intact.

NOTE:

(a) Standard Electricity North West designs (apart from metal-clad padmounts and compacts) will be SAFE if EPR<3kV and protection operates within 1 second. The requirement to achieve this without Network Contribution provides some contingency for loss/replacement of large sections of lead sheathed cables but does not consider a complete loss of sheath continuity between source substation and new installation. If a substation forms part of a loop (e.g. a normal 'open ring' network) there will generally be a duplicate connection (via each cable sheath to the wider network and ultimately back to source) and the risk of there being no metallic return path for Earth Fault Current is correspondingly reduced. The likelihood of losing a return path is small, particularly with modern triplex cables, but good engineering practice must be followed to minimise this risk. Single points of failure (e.g. single bolted sheath braids and/or teed connections) introduce an increased risk because the connection is less reliable. Electricity North West has assessed the risk to personnel and to the public and (even for teed connections) the risk is considered acceptable.

(b) A 2kV EPR limit will be SAFE for 1 second faults if a standard Electricity North West layout is used where the touch voltage is 10% of the EPR, in which case the maximum touch voltage will not exceed 200V. Step Potential outside the site needs to be considered in certain situations (livestock or wet/barefoot activities), and electrode re-positioned if necessary. Nether the less Hot sites must consider the safety of public outside the substation and follow sections 5.5 and 5.6.

(c) LV requirements are not described in detail in this document. Refer to CP332.

(d) These design rules assume that the new installation is clear of Hot zones caused by other substations / towers (e.g. 400kV infrastructure). Refer to Section 5.6 if this is not the case.

The use of Network Contribution in calculating EPR is summarised in the table below.

RULE	DESIGN REQUIREMENT	ALLOWED TO RELY ON:			
		SUBSTATION ELECTRODE	ELECTRODE EFFECT OF SUPPLYING CABLE	PARALLEL FAULT CURRENT PATH	NETWORK CONTRIBUTION (INTACT NETWORK)
1	Substation must be safe in terms of touch	✓	✓	✓	✗
2	The resistance of the HV electrode system in isolation of the network shall not, exceed 10Ω unless special circumstances require.	✓	✓	✓	✗
3	The substation shall be designed to Cold where reasonably practicable, i.e. its EPR must not exceed 430V.	✓	✓	✓	✓
4	The EPR must not exceed 3kV	✓	✓	✓	✓

8.3 Rules for Pole Mounted Substations

(a) The HV electrode resistance shall not exceed 40Ω (11kV systems) / 25Ω (6.6kV systems). Where surge arrestors are used the maximum resistance including the same network contribution elements for ground mounted substations described in the previous subsection shall not exceed 10Ω, unless special circumstances require.

(b) The LV electrode system (and neutral/phase conductors) shall be segregated from the HV electrode to prevent danger occurring on the LV network following a HV network fault (ESQCR regulation 8).

NOTE:

In-soil HV-LV electrode separation shall be at least 9 metres, or more for Lo/Hi soil models. For overhead LV systems, the LV electrode shall be installed at the first pole. Separation distances may be determined by desktop study, Appendix B Table B2, or without study if greater than 50 metres.

The earthing arrangements are described in CP420 Part 1 Chapter 21 and are the preferred design for Electricity North West's 11/6.6kV pole mounted distribution transformers and equipment.

(c) Sufficient HV electrode must be installed to meet surface current density requirements (Section 5.1.4).

(d) Installations such as GVRs and ABSDs which do not have LV electrode systems may be installed to standard designs. A prerequisite of using a standard design is a site risk assessment to confirm the site is not in a high-risk location.

A high risk location is an area likely to be frequented by the public, for example near footpaths, children's play areas, or built up areas. The site must be at least 50 metres away from existing LV electrodes such as metallic services, PME earth electrodes, street furniture.

Standard arrangements are referenced in CP420 Ch21 and shown in detail in CP430 Part 1.

Access to all metallic equipment connected to the HV earth shall be in accordance with CP606 S15.

8.4 How to Proceed

Complete the assessment outlined in Section 5.1 to determine if the site qualifies as a 'Type 1' site or otherwise, or follow the flowchart given in Fig. 1 above. The steps are further detailed below.

8.4.1 Type 1 (GES) Sites

A Type 1 site is described in Section 5.1. It will be part of a 'Global Earthing System', i.e. it is connected to a dense interconnected mesh of cables (often lead sheathed), substations and bonded metalwork including LV systems, metallic water pipes and gas pipes, etc. Together these serve as a large distributed electrode system providing a very low contact resistance with Earth, and furthermore acting to equalise the voltages around the substation under fault conditions.

These factors, together with a cable connection to an impedance earthed substation, are all favourable in terms of earthing design since they serve to minimise the EPR.

Section 5.1 provides a simple check-list for Global Earthing Systems, summarised here:

(a) Fault current is low (impedance earthed source) – less than 2kA

(b) Fault current flowing into soil (I_{GR}) is reduced significantly by a continuous cable sheath from the source (which carries majority of current back to source), i.e. no overhead line or other break in continuity. I_{GR} typically less than 250A.

(c) A wide area Network Contribution of 0.25Ω or less acts in parallel with the new substation's electrode. The LV and HV systems are combined meaning that parallel paths for fault current return are created, increasing security and reducing risk from broken HV cable sheath.

(d) Sites which qualify will be Cold. They must be based on a standard layout (Appendix A) which is suitable for GES, i.e. the touch voltage must be less than or equal to 10% of the EPR, and the metalwork must be enclosed in a GRP enclosure or building structure (not with metallic fence). Third party substations meeting these criteria are also acceptable provided that touch voltages have been calculated using an appropriate soil model (Section 14). Integral substations shall preferably have GRP or timber doors. Where steel doors are unavoidable, the standard design with the extended earth mat shall be used. If it is not possible to touch any metal connected to the HV earth and the door simultaneously, the door may be left unbounded. It is assumed GES substations will be in urban areas and hence the likelihood of members of the public being barefoot is extremely low, and Safe touch voltages have been determined on this basis. If it is suspected a particular installation may be in an area where people are barefoot, the requirements of Appendix C apply.

Refer to the worked examples in Appendix D.

Electricity North West's favoured practice is to install additional HV electrode with HV cables, and LV electrode with LV cables. HV/LV earthing shall be combined by closing the removable link (Section 5.5).

Confirm by measurement after installation that the substation earth resistance DOES NOT EXCEED 10Ω (Appendix E).

8.4.2 Type 2 Sites (Basic Assessment)

If a site does not qualify as GES above, it will be necessary to carry out a 'basic' assessment using typical values.

The following basic assessment shall be repeated for ALL running arrangements / supply configurations:

(a) Establish the approximate maximum Earth Fault Current at the source substation; typically, 1kA per transformer for impedance earthed sites, and 10kA for solidly earthed substations.

(b) Use Electricity North West's earthing calculator tool to calculate I_{GR} (Ground Return Current) and EPR (Earth Potential Rise). A value of R_A should be ascertained from Electricity North West's database; alternatively, a figure of 0.1Ω may be used for this basic assessment.

(c) If source substation is Hot, additionally calculate transferred EPR using the tool – this is the voltage carried along the cable sheath from the primary/grid substation. Not applicable if any overhead line is in circuit.

(d) When entering R_B into the tool, choose 10Ω initially, or if soil resistivity is known, the appropriate value of R_B should be read from the tables in Appendix A. This is the typical resistance value that will be achieved for a standard arrangement. Approximate regional soil resistivity can be found from online sources.

(e) If EPR < 2kV, multiply it by the touch voltage percentage (Table A1) to determine the touch voltage. If this is below 233V, the site is SAFE. If not, try again with lower R_B, establishing the acceptable R_B value that must be achieved.

NOTE:

If the substation is indoors/dry, and cannot be touched from outside (e.g. leaning in through open door), a higher figure of 298V may be considered which reflects the additional contact resistance of a dry concrete surface. These figures assume all faults will clear within 1 second.

(f) Make an assessment of Network Contribution (R_{NET}) [Table 2] and enter this into the tool in place of R_B to determine if the site is Hot or Cold. If marginal, include R_B in parallel with R_{NET} and explore whether moderate reduction of R_B can make the site Cold.

NOTE:

A Cold substation is preferred wherever possible. If a Hot substation is to be installed in an existing network, it may not be possible to achieve segregation between HV and LV systems due to physical constraints, particularly if neighbouring substations operate combined HV/LV earthing (i.e. designed/assumed Cold). In such circumstances the designer should take appropriate measures to render the new substation Cold and operate with combined HV/LV earthing. The requirements of section 5.5 apply to all Hot substations.

(g) Having established the required Target Resistance (R_B), determine (from tables in Appendix A) if this can be achieved with a standard Earthing System or whether the system needs to be augmented with additional electrode. This will require a knowledge of soil resistivity, for which online sources are sufficient at this stage. If online resources are used, a factor of safety shall be introduced by limiting EPR to 380V. Site measurements shall be required to determine ground resistivity. If requirements are modest, and the '4 rules' of Section 5.3 are satisfied, the design is (almost) complete.

(h) Confirm that the surface area of the electrode system is sufficient to carry the full (worst case) Ground Return Current (I_{GR}) for 3 seconds (Table B6).

(i) If electrode requirement is overly onerous, or other factors prevent a standard substation being installed, the design should be treated as 'Type 3' as described below.

8.4.3 Type 3 (Detailed Assessment)

Having undergone a basic assessment as above, there will usually be some sites where a SAFE and/or Cold site cannot easily be achieved. For these, it will be necessary to make a more accurate assessment of the requirements based on actual rather than assumed values, and (in the case of non-standard layouts) to carry out modelling as necessary to ascertain the touch voltages around the substation.

The 'Basic Assessment' described in Section 5.4.2 makes assumptions which, whilst expediting the design process, may produce a sub-optimal design that is either inefficient (i.e. wasteful / overdesigned) or unsafe. The assumptions used above use engineering judgement so that an unsafe design is highly unlikely, however the following optimisations should be considered for all 'Type 3' cases:

5.4.3.1 Fault Current Magnitude and Current Split

Fault current decays along a feeder, and is also influenced by the Earthing System impedance. Accurate knowledge of the cable/line self and mutual impedances will allow the fault current to be estimated. Electricity North West has an Excel tool which will provide I_{GR}%, i.e. the 'split' of current between cable sheath and ground. This should be used for all cable-connected substations. If any supply (including alternate running arrangements) uses overhead line for all or part of the route, the full Earth Fault Current should be used as the Ground Return Current, i.e. I_{GR}% = 100%.

Rather than use the full primary substation fault level, benefit will be gained from using network modelling software to find the Earth Fault Current (I_F) at the point of connection (POC). I_F should be calculated for all running arrangements. Further refinement can be obtained by including the fault impedance (R_B) for overhead fed systems, since this plays a significant role in limiting current, for example an 11kV phase-to-Earth Fault at a standalone substation (10Ω electrode) cannot normally exceed 635A, whereas the 'zero ohm' fault current produced by modelling tools will often vastly exceed this.

5.4.3.2 Primary Substation Earth Resistance and EPR

Using Electricity North West's earthing tool, or carrying out longhand calculations requires knowledge of R_A and R_B. R_A is the resistance of the primary substation's Earth Electrode system, and can be found from Electricity North West's earthing database. R_B is the (target) resistance for the new substation.

It is important also to use the database to establish if the source (primary or grid) substation is Hot, since this can cause a cable connected secondary substation to be Hot due to voltage transfer along the cable sheath. If a new substation is to be fed from a Hot primary and is within 500m or is the first on the feeder, it should also be treated as Hot. If this proves problematic, a calculation of voltage drop in the cable sheath will indicate if this is true (Electricity North West's earthing design tool can do this for most cable types and should be used where possible). Lowering R_B can help to reduce the transferred potential below 430V* in some cases.

NOTE:

that if the source substation is Hot due to an EHV fault that clears in 0.2 seconds or less, a limit of 650V applies to transferred potential to a substation that is designed to be Cold.

NOTE:

also that if the new substation is in a Hot Zone of a 132kV or 33kV substation then the HV and LV must be earthed separately. The LV electrode(s) must be outside this area, or studies conducted to confirm that their rise of potential will not exceed 430V (or 650V as appropriate). Refer to CP278 for more details, and Section 5.6.

5.4.3.3 Protection Settings

The approaches outlined above assume that protection will clear Earth Faults within 1 second. In many cases, IDMT or instantaneous Earth Fault protection will operate to interrupt current much faster than this, meaning that permissible touch voltage limits are higher (Appendix B). The actual protection clearance times may be used (with care) if achieving a Safe Site is otherwise problematic. Caution is needed if protection settings are liable to be altered, or remotely controlled, and if there is any doubt, worst-case (slowest) clearance should be used for the lifetime of the installation as described in Section 8.

Secondary protection (e.g. GVR / Auto-recloser or similar) may provide very fast clearance, for which a site may be SAFE for very high touch voltages. Since secondary protection can be disabled or may not be reliable, the following rules may be applied:

Additional Rule 1:

> If fast secondary protection is used in design calculations (i.e. the site is SAFE without Network Contribution, but for fast protection operation only), the site must also be safe with primary protection settings applied, but Network Contribution may be allowed in this assessment.

This is a relaxation of Rule 1 (Section 5.2) requiring a site to be safe without Network Contribution, because a coincident failure of secondary protection and network connections is considered to be a double fault and unlikely to occur.

Even for very fast (<0.2 sec.) HV protection clearance times, the 430V threshold shall be used for Hot/Cold classification and for choosing LV electrode position at a Hot site. Electricity North West currently does not have any very fast, high reliability protection at HV.

5.4.3.4 Network Contribution

Once the HV cable sheaths / screens are connected to the substation, the overall Earth impedance will be reduced, as the remote Earthing Systems from the underground distribution network contribute in parallel with (and often swamp) the substation electrode resistance. The parallel Network Contribution can be significant, especially where there are substantial lengths of PILC or PILCSWA cables as is the case with most existing networks.

Provided the substation can be made SAFE from an operational touch potential perspective (in accordance with 5.4.2 Rule 1) without any Network Contribution, the Network Contribution may be utilised at the design stage to achieve (or contribute towards) a Cold site. A Cold site fortuitously provides multiple connections to the wider network via HV and LV cable sheaths.

If the cost of making a site SAFE without Network Contribution is disproportionate / uneconomic, the advice of ENWL's suitably qualified staff shall be sought.

Network contribution may be estimated using Electricity North West's Excel tool, or in accordance with ER S34. The contribution of the supplying cable shall be considered. Additional contribution from teed circuits and intermediate substations may be included.

The contribution should be modelled or measured if practicable.

5.4.3.5 Soil Resistivity Model

The design requires a measurement of soil resistivity using methods described in Appendix E. The soil resistivity informs the extent of electrode system / augmentation required, and influences the Network Contribution, if any. This knowledge is important in deciding whether a design is practical to install. A Lo/Hi soil model may additionally extend the size of any Hot zone and require larger HV/LV separation distances. Refer to Table B2 in Appendix B.

If a substation design has been described as 'Type 3' because electrode requirements appear excessive, an assessment (measurement) of soil resistivity may in fact reveal that a lesser electrode system will suffice, if the soil resistivity is found to be better (lower) than expected.

This document generally considers the soil as a single, uniform structure. In practice, the soil may comprise 2 or more layers, and if these layers have significantly different resistivity this will influence the extent of voltage contours around the substation (and thus radius of 'Hot zone' where relevant). For sites where underlying ground may be rock / shale, covered with a relatively thin layer of soil, it will be necessary to install horizontal electrode instead of vertical (rod) electrodes. Hot zone radius is also likely to be larger. The advice of Electricity North West's Suitably Qualified Staff should be sought if necessary, as in most situations specialist modelling / calculation will be required to fully explore these effects. If site specific measurements are required the method described in Appendix E should be used.

8.5 Hot/Cold Requirements

8.5.1 All Sites

All sites (pole mounted and ground mounted) will experience a potential rise (EPR) under HV fault conditions. If this exceeds 430V (i.e. the site is HOT), the LV earthing system must be kept separate from the HV earthing system to limit the rise of potential on LV earth(s) during the HV fault. Additional actions are also required as described below.

It is rare for overhead line fed pole mounted equipment to be COLD (i.e. EPR <=430V), but if this can be achieved, the HV and LV systems may be combined. It is more usual for all pole mounted equipment to be designed HOT, with LV electrode(s) placed well clear of the HV system. Section 5.1.2 describes standard arrangements for pole mounted equipment, and includes references to relevant ENWL documents. Standard pole mounted arrangements with segregated HV/LV earthing are preferred whether the site is HOT or otherwise, unless specific reasons exist that prevent segregation being achieved. For single LV customers, PNB earthing arrangements may be appropriate.

If HOT sites are likely to be close to third parties, buried services, or animals, ENWL must estimate the size of any 'HOT zone' around the substation and its electrodes and inform the third party if their equipment is likely to be affected, or otherwise take appropriate actions to prevent danger (e.g. by making the site COLD or by reshaping the contours). The easiest way to satisfy this requirement is to plot the soil surface voltage contours using software such as SAFEGRID or similar, or to use standard formulae (ENA EREC S34) to estimate the extent of the 430V, 650V and/or 1150V contours. Risk assessment may be appropriate for some sites where the HOT contours are found to impinge on existing areas, see 5.6 below.

8.5.2 Additional Actions at Ground Mounted Sites

A Cold site is preferred where possible, since Hot sites introduce additional requirements. The following items are necessary at ALL Hot ground-mounted substations, in addition to those described above:

- Separate HV and LV earth electrodes are required as shown in Figure 3 but they are preferably combined at Cold Sites. At Hot Sites the Earth link in the LV cabinet shall be removed to segregate the HV and LV Earths (shown arrowed in Figure 4). Care must be taken to ensure that small wiring etc. does not provide a bridge across the HV-LV separation. This includes all control and metering panels.

Fig. 3 – Ground-Mounted Substation Earthing System Showing Typical HV and LV Earthing Arrangements

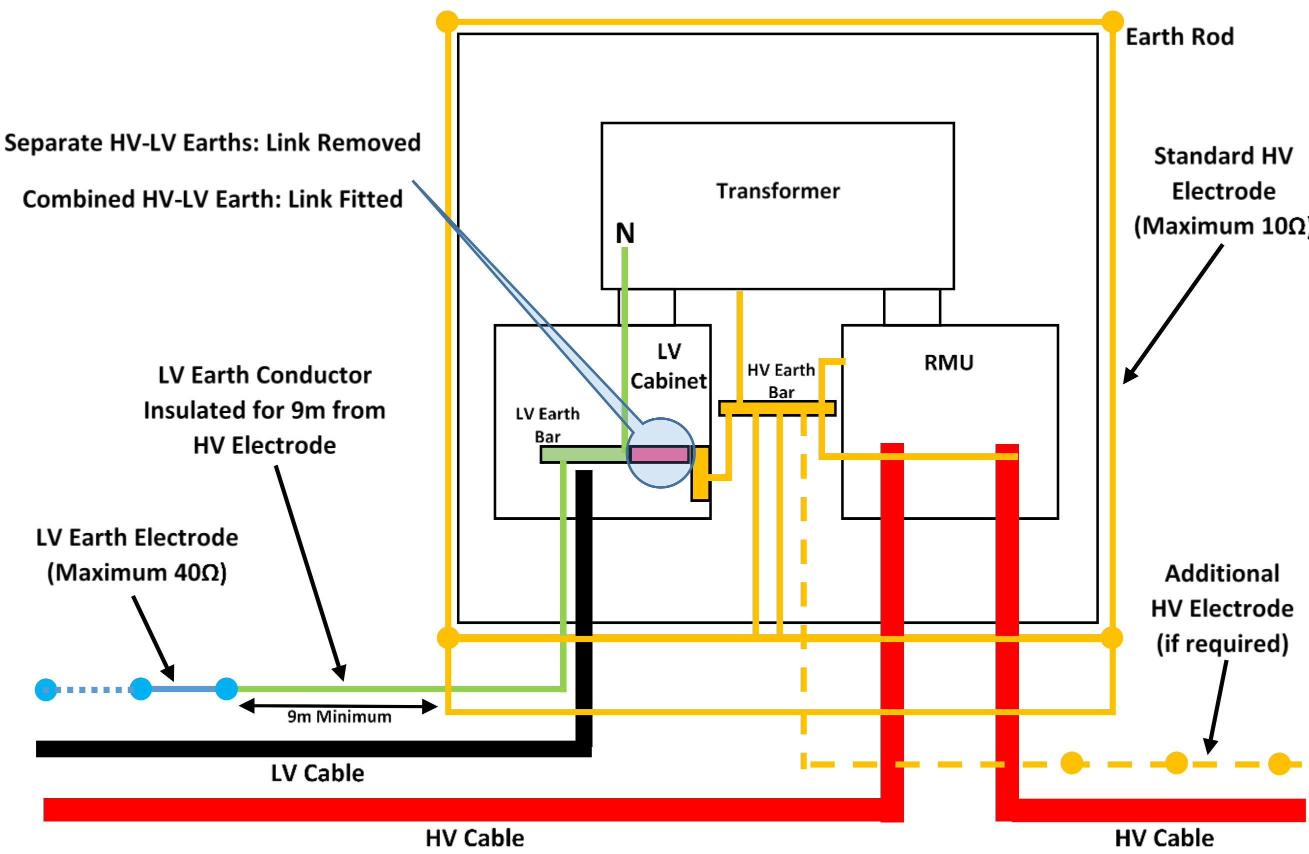


Fig. 4 – Typical HV – LV Earth Link (Combined HV and LV Earthing Systems Shown as Link is Present)

- The designer must establish the size (radius) of the 430V contour around the substation. This shall be recorded, and if necessary communicated to relevant third parties. This can be calculated using formulae in ENA ER S34, or by computer software.

- The substation maximum EPR must not exceed 2kV (in service with normal network connections). If a customer has agreed that a higher EPR is permissible, this shall be fully documented.

- A separate LV electrode is required. This must be sited away from the HV system, in particular it must lie outside the 430V contour. The designer shall determine the safe separation from the HV electrode, buried metalwork connected to the HV Earth, and any PILC/PILCSWA HV cables. LV cable screens and the LV Earth conductor must be insulated from Earth (PVC covered and/or ducted) within this 'Hot Zone'. Table B2 shows the separation, in ground, that is required between electrode systems. A larger distance may be required where low resistivity soil is over poor (e.g. rock/shale) lower layers.

- Inside the substation, there exists a hand-to-hand shock voltage risk, due to the possibility of the LV Earth being at a different voltage to the HV Earth. Care must be taken to maintain a 2m separation between metalwork connected to different Earths. Substation lighting and power shall be removed from LV cabinets, due to risk arising from using earthed 230V equipment.

- Any LV supplies provided to the Hot substation (including those for local RTU etc.) shall be via an isolation transformer with a suitable withstand voltage (to BS 61558-2-4) and in any case no less than the worst case EPR (3kV). This is true even if an LV Earth is not required for the equipment, since the LV neutral (and phase) insulation can otherwise be stressed inside the equipment under HV Earth Fault conditions. Appropriate warning signs shall be fitted, refer to CP278.

See Appendix C7 for additional requirements with HV metering / customer substations.

8.6 Additional Actions – for Equipment within Hot Zones

If a Hot zone around a substation extends to include LV equipment, or a dwelling, it can create a hazard resulting from touch voltage at that location, or may cause transferred potential to be carried to a remote location where it can be a hazard. Where possible, the situation should be avoided at the design stage, by careful use of electrode to control the shape (or size) of any Hot zone.

If the situation is unavoidable, and eliminating the Hot zone (making Cold) is not practical, the advice of a specialist or suitably qualified person should be sought. In most cases a risk assessment will be warranted, which will inform the extent of mitigation (if any) required to reduce the risk to tolerable levels. Refer to ENA EREC S34, ENA TS 41-24 and BS EN 50522, as well as HSE R2P2 publication (Reducing Risk, Protecting People).

The Individual Risk (IR) per year is the product of P_E (probability of exposure), P_{FB} (probability of fibrillation) and f_n (faults/year) and must not exceed 1 in 10,000 fatalities per person per year for members of the public (or 1 in 1000 for workers). An IR of 1 in 1,000,000 is deemed to be 'Broadly Acceptable'. For values between 1 in 10,000 (1000) and 1 in 1,000,000 this is the ALARP (as low as reasonably practicable) region for which the cost of mitigation must be assessed.

$$IR \cong \; f_n * P_E * P_{FB}$$

In many cases, if the LV system encroaches in a Hot zone, if the LV system is part of a larger system with the majority of its electrode away from the Hot area, the Hot zone will be distorted around the LV system so in fact there is unlikely to be any risk at all; effectively the voltage rise on the LV will be pulled down by the (PME) electrode (etc.) away from the Hot zone. Computer modelling or detailed calculations are required to confirm this.

9 Preferred Earthing Arrangements (Ground Mounted)

9.1 Overview

Electricity North West standard designs are described in detail in Appendix A.

Each design includes an Earth Electrode system with a horizontal ring of bare copper conductor encapsulating all exposed metalwork to provide an area of lower touch voltages. Where the substation enclosure is non-metallic the horizontal ring may be installed around the edge of the foundation. Where the substation enclosure is metallic, e.g. a padmount substation, then the horizontal ring is offset from the exposed metalwork by up to 1m, so that it is buried under the feet of any person touching the equipment. The ring shall be installed at a depth of 0.5m or greater to ensure it remains in stable (wet/damp) soil.

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

The horizontal ring is supplemented by four Earth rods located at each corner of the substation perimeter electrode; primarily to reduce Earth resistance and lower EPR.

Indoor substations make use of a rebar mesh under the equipment, or over the entire substation floor to establish an equipotential area. This mesh is bonded to the Main Earthing System at regular intervals. Dedicated electrodes provide contact with soil and limit EPR.

9.2 Acceptable Variations to Standard Design

The main parameters that can be varied by the designer are (1) the length of Earth rods, and (2) the extent of any additional electrode (if any) installed outside the footprint of the substation. No other variations of the standard design are permitted without the authority of Electricity North West's suitable qualified staff.

The designer should follow the approach outlined in Section 5.4 to determine the extent of electrode required.

If additional electrode is required, further guidance can be found in Appendix B.

10 Jointing and Connection of Earth Systems

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 CP411 Pt1 N Standard Technique 10 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.

10.1 Ancillary Metalwork

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. Steel access doors (that may be touched from outside the substation) are 'grey areas' in that there are pros and cons to bonding. 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 (subject to special conditions mentioned in Appendix C), but if they are to be bonded on a Hot site, additional measures are required to minimise touch voltage 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. Bonded steel doors may be used in Type 1 designs if the standard extended HV earth mat is used.

Care should be taken at Hot sites if any LV equipment is mounted on HV-earthed steelwork. Refer to Section 5.5.

10.2 Decommissioned Lead Covered Cables

Where lead covered cables are decommissioned, the benefits of lead sheath acting as an additional horizontal electrode shall be retained. This shall be achieved by connecting the lead sheath to the substation HV earth system, and/or the screen of new HV cables using approved joints.

Refer to CP411 Pt2 N Section 2, Standard Technique 63 for further detail on the procedure for connecting decommissioned lead sheathed cables to substation HV earth system. June 22

11 Fault Clearance Time and Fault Levels

The tolerable body current limits, and thus step and touch voltages are a function of (normal) fault clearance time. The fault clearance times detailed in Table 3 shall be applied for touch and strep voltage calculations on the Electricity North West system unless it can be shown that protection will reliably operate faster than these limits, for the lifetime of the installation.

NOTE:
Formulae in Appendix B9 may be used to calculate clearance times from protection settings, if these are known, and can offer some design economy for Type 2 or 3 assessments.

Table 3 – Design Maximum Fault Clearance Times (Normal Protection Operation)

VOLTAGE	FAULT CLEARANCE TIME

132kV	0.2s
33kV	0.5s
11/6.6kV	1.0s

The figures above relate directly to EPR / touch voltage limits.

The Earthing System shall be designed to withstand slower 'backup' protection operation. For 11kV and 6.6kV systems the backup clearance time is **3 seconds**. This is considered a rare event, following failure of primary protection. The substation touch voltages need not be based on this figure, but thermal ratings of conductors and electrodes must ensure that failure does not occur during this period. Conductor sizing requirements in Appendix B are based on this figure.

The Electricity North West 11kV and 6.6kV system is impedance earthed, typically Earth Fault Current is limited to 1000A per transformer or maximum **2kA** at most primary substations. This fact is key to the Electricity North West earthing design; if any substation is solidly earthed, or impedance devices are bypassed for any reason, higher fault levels (and EPRs) will result. If the designer becomes aware of Earth Fault levels in excess of 2kA, the design will most probably fall into the 'Type 3' category and the advice of Suitably Qualified Staff should be sought.

Phase-to-phase fault levels at Electricity North West distribution substations can exceed this figure by a considerable margin. It is not necessary to design the Earthing System at these new-build substations to withstand phase-to-phase fault current.

12 Installation Requirements

The substation Earthing System shall have Earth conductors sized in accordance with Appendix A below. The conductors forming the Earth grid are loop connections and should be sized accordingly. Only copper conductors shall be buried.

Horizontal electrode must be in contact with bare soil. It shall not be backfilled with sand or similar material 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. Consideration shall be given to legal protection of grids installed in third party owned land.

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

13 Soil Resistivity

The resistance of a standard Earthing System, and thus the substation EPR and touch voltage are directly related to soil resistivity.

An initial assessment of the earthing design, demonstrating the sensitivity of calculated quantities to a variation in ground resistivity, can be made using typical values based on the soil type. This method does not however take account of ground variation and should be used for initial assessment only (Basic Assessment of Section 5.4.1 and 5.4.2). Table 4 provides typical ground resistivity values (Reference ENA TS 41-24).

Table 4 – Typical Ground Resistivity Values

GROUND TYPE	RESISTIVITY (ΩM)
Loams, garden soils etc	5 to 50
Clays	10 to 100
Chalk	30 to 100
Clay, sand and gravel mixture	40 to 250
Marsh, peat	150 to 300
Sand	250 to 500
Slates and slatey shales	300 to 3 000
Rock	1 000 to 10 000

Various sources of soil data exist, including British Geological Survey data. However, greater detail can always be obtained if a measurement is possible, and the designer should consider requesting a measurement where necessary. Site measurements shall be taken for Hot sites.

The ground resistivity at a site is easily measured using the Wenner method, using traditional Earth resistance testers with four electrodes, and this method will provide data about soil layers if sufficient space is available for a detailed measurement (typically ≈ 150m).

Measurement techniques are described further in Appendix E.

NOTE:

In rocky areas (e.g. Lake District) the designer should be aware of the limitations of uniform soil, primarily the extended Hot zones that can occur when 2 or more layers are present and the upper layer(s) are much lower resistivity than the underlying bedrock. This will influence the HV-LV separation distance for such 2-layer soil combinations, as shown in Table B2.

14 Design Records

For all earthing installations used for distribution substations, a record shall be kept of any measured resistances, in particular overall resistance (substation earth and network contribution) values shall be measured and recorded.

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.

15 Ground Mounted Transformer Connections

Although not strictly an earthing problem, the following details are important to distribution substation design, and in particular the points relating to neutral earthing.

- New ground mounted transformers will normally be fitted with transformer mounted fuse cabinets. These are directly bolted onto the transformer LV terminals, and consequently there is no cable connection. This method is preferred.

- If a separate LV fuseboard is fitted, a high standard of workmanship is essential for the cabling between this fuseboard and the transformer LV terminals. This is because the cables and the LV busbar are in the HV protection zone of the transformer. The HV protection is rather insensitive to LV side faults and clearance times are quite long.

- In all cases the LV neutral to LV Earth connection should be made within the LV fuseboard cabinet. In the case of a separate LV fuseboard this ensures that if an Earth Fault occurs between the LV busbar and the fuseboard frame, the fault current returns to the transformer star point via the neutral conductor. The frame of separate LV fuseboards should be connected to the LV Earth system.

- Reference may be made to Electricity North West's jointing code of practice CP411 Pt1 N and Appendices C and E of CP258 if further detailed guidance on transformer LV cable installation is required.

- Where it is necessary to separate the HV and LV Earths the following points shall be considered:

  - The minimum separation allowed between HV and LV Earth Electrodes is 9m, but a greater distance is preferable if space permits. In all cases the designer needs to determine the minimum separation. On overhead systems it is usual and desirable to connect the LV Earth Electrode to the neutral at the first pole out from the substation.

  - The metallic sheaths of 11/6.6kV and LV cables (and bare electrodes) must be insulated wherever they encroach into the influence zone of the other Earthing System (less than 9m separation). Effective insulation will be provided by a 0.8mm radial thickness of PVC sheathing (heatshrink 'cable wrap' may be used), or installation in plastic ducts.

  - LV cable sheaths should be terminated so that they are insulated from any metal connected to the HV Earth.

  - Where a transformer mounted fuse cabinet is used, it will be necessary to remove any link connecting the cabinet frame to a LV combined neutral/Earth busbar or LV Earth bar (if separate neutral and Earth bars are provided). NB if separate LV neutral and LV Earth bars are fitted, they will require a bolted link to be fitted to connect the two, this being a different link to the one involving the cabinet frame. Insulated gloves may be necessary in proximity to open LV cabinets, and 13A sockets should be removed/disconnected. Refer to CP278 and Section 5.6.

  - The cabinet frame and all transformer steelwork is connected to the HV Earthing System therefore the LV neutral earthing will normally require a PVC insulated cable to connect between the LV neutral/Earth (or LV Earth) busbar and the LV electrode.

- For these cases of separate HV and LV earthing combined with transformer mounted fuse cabinets, a fault between an LV phase and the cabinet will probably remain uncleared, and all precautions must be taken to prevent the occurrence of such a fault.

16 Measurements

Measurements shall be undertaken at different stages of the design and construction as described in Table 5. Measurement methods are described in Appendix E.

Table 5 – Measurements Required During Design and Construction

DESIGN / CONSTRUCTION STAGE	MEASUREMENT REQUIRED	NOTES
During planning – Type 3 and some Type 2 (Hot) designs.	Soil resistivity measurements (Section E4).	
On installation of substation electrode (including any extended electrodes) before connection of HV cable sheaths.	Earth resistance measurement using either Fall-of-Potential (Section E5) or Comparative Method (Section E6.1).	Resistance of 10Ω or lower required.
On installation of substation electrode (including any extended electrodes) after connection of HV cable sheaths.	Earth resistance measurement using Comparative Method – Clamp Meter (Section E6.2).	Resistance of 10Ω or lower required.
For Type 3 design, after installation of substation electrode and connection of 11kV cable sheaths.	Earth resistance measurement using Fall-of-Potential (Section E5).	To confirm overall Earth resistance.
During construction after each Earth conductor joint is made.	Joint resistance test (Section E8).	Test all connections to earth bar. Other joints may be tested in series.
Prior to energisation.	Plant bonding test (Section E7).	Resistance of <20mΩ between plant and Earth bar.
At substations with separate HV and LV Earths prior to energisation.	Separation test (Section E9).	R3 to be <=0.9(R1 + R2).

The results shall be recorded and held for future reference in Ellipse.

17 Guidance for ICP and IDNOS

All earthing designs must comply with the requirements of ENA TS 41-24. The main requirements are to satisfy touch voltage limits, and NOT export dangerous potentials onto the LV network.

Refer to the Electricity North West ES333 Earthing Design for IDNO 6.6/11kV Distribution Substations

Unless network specific data has been used by the third party, the following limits / information will be given to the third party on request:

- Assumed 1 second clearance time.
- Circuit data / cable types – for all running arrangements from source to new substation.
- EPR limit of 2kV.
- Touch voltage limit of 233 volts (soil) or 298 volts (dry concrete or deep chippings).
- LV network transfer limit of 430V.
- Whether a 'Type 1 / GES' design applies.

A design satisfying Electricity North West's requirements described herein will meet these limits. For maximum allowable EPR (2kV), a maximum touch voltage limit (as % of EPR) of 12-15% applies to achieve a Safe Site; this will normally necessitate a Stance Earth or buried rebar / mesh under the operator position. The third party shall provide calculations or computer modelling evidence as appropriate and this must meet the approval of ENWL if the substation is to be adopted.

Independent Distribution Network Operator (IDNO) substations shall, in general be designed to similar standards. IDNOs should be encouraged to use ENWL standard arrangements and design a site with an EPR below 430V wherever possible. However ENWL cannot insist on a particular value of EPR or whether combined/separated LV earths are used, as ENWL is not responsible for the substation or the LV network. However the substation must be safe for ENWL staff to enter and operate and this shall be demonstrated in the design submission. Ultimately all designs must comply with ENA TS 41-24 and BS EN 50522:2010.

18 Documents Referenced

DOCUMENTS REFERENCED	
Construction (Design and Management) Regulations	
Electricity Safety, Quality and Continuity Regulations	
HSE R2P2	Reducing Risk, Protecting People.
BS EN 50522	Earthing of power installations exceeding 1 kV a.c.
BS EN 50443	Effects of electromagnetic interference on pipelines caused by High Voltage a.c. electric traction systems and/or High Voltage a.c. power supply systems.

BS EN 62305	Protection against Lightning.
BS 951	Electrical earthing. Clamps for earthing and bonding. Specification.
BS 7430	Code of practice for protective earthing of electrical installations.
ENA EREC S34	A Guide for Assessing the Rise of Earth Potential at Electrical Installations.
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 TS 41-24	Guidelines for the Design, Installation, Testing & Maintenance of Main Earthing Systems in Substations.
Distribution Safety Rules.	
EPD333	Supply System Earthing.
Electricity North West Guidance	Guide for ICPs / IDNOs on Earthing Design.
CP215	Supplies to Mobile Phone Base Stations with Antennae on High Voltage Structures.
CP258	Connections for Industrial & Commercial Customers.
CP278	Supplies to Hot Sites
CP314	Lightning Protection of High Voltage Overhead Line Systems.
CP332	LV Service Connections & Application of PME.
CP335	Earthing Design for 33kV & 132kV Grid and Primary Substations and Equipment.
CP411 Pt1 N	Mains Practice up to and including 132kV. Cable Jointing up and including 1000 Volts.
CP420 Part 1	Policy and Practice for Wood Pole Overhead Lines.
CP430 Part 1	Overhead Line – Linesmen's Manual – Wood Poles.
CP684	The Use, Inspection and Maintenance of Ancillary Engineering Equipment.

19 Keywords

Earthing; Substation.

Appendix A – Standard Earthing Arrangements

A1 Electricity North West Standard Substations

The standard Electricity North West secondary substation earthing designs are listed in Table A1 together with their associated drawing numbers and key design data. The supporting calculations are provided in Document ESL2291-R02.

Table A1 – Key Design Data for Standard Secondary Substation Earthing Arrangements

SUBSTATION ARRANGEMENT	DRAWING NO.	WORST CASE ACCESSIBLE TOUCH VOLTAGE (% OF EPR)	RESISTANCE IN 100ΩM UNIFORM SOIL RESISTIVITY (Ω)	SURFACE CURRENT DENSITY REQUIREMENTS	
				TOTAL SURFACE AREA (X10^5 MM^2)	SOIL RESISTIVITY WHERE REQUIREMENT MET
Schneider GRP Unit 11kV	ESL-900350-002	9.1	9.0	7.88	up to 300Ωm
Schneider Compact 11kV	ESL-900350-007	20.5	9.5	7.55	up to 300Ωm
Schneider Standard Mini 11kV	ESL-900350-008	20.5	8.9	7.31	up to 300Ωm
Schneider Maxi 11kV	ESL-900350-009	19.8	8.6	7.54	up to 300Ωm
Schneider Extensible Switchgear in GRP Housing	ESL-900350-014	8.2	8.0	8.94	up to 300Ωm
Schneider RMU & Metering Unit	ESL-900350-016	8.7	9.0	9.26	up to 300Ωm
Typical Brick Housing for External Substation	ESL-900350-026	8.1	9.0	12.60	up to 300Ωm

The requirements for substations integrated into a building / basement are described in Section A.2. Calculations have shown that a steel mesh (rebar or surface laid within a screed) and connected to the substation earthing system will limit touch voltages within the substation to lower than 10% of the EPR.

A1.1 Common Features of all Arrangements

(a) The standard arrangements are applicable to distribution substations associated with an underground 11/6.6kV cable system where the dimensions of the substation are not greater than 5m x 5m, housing floor mounted 11/6.6kV equipment with footing dimensions of not more than 2m^2. If these criteria are not met then refer to the design principles given in CP335.

(b) The basic arrangements comprise a loop of buried bare copper conductor, with Earth rods or additional electrode connected in order to achieve a calculated Target Resistance. A central marshalling bar (busbar) should be used to facilitate future testing / alterations, with each connection clearly labelled. The marshalling bar shall be 150mm above floor level.

(c) Where several connections feed into a single marshalling bar, the conductors should be kept apart throughout their length and in particular below ground in order that a clamp meter can be used to measure the contribution from each part.

(d) The perimeter loop should terminate on two adjacent lugs on the main marshalling bar. The resistance around this loop shall be measured and recorded at commissioning (it should be less than 0.1Ω). It can then subsequently be measured using a clamp meter, to confirm its continuity, or both legs can be bunched together in the clamp-meter jaws (without touching each other) to provide an approximate measurement for its Earth Electrode contribution, normally in the order of 5-20Ω.

(e) Additional conductor shall be laid with the incoming HV cables if the site is Cold, including the contribution from this conductor. It shall be connected to the HV Earth bar. The external buried copper conductor to be laid in cable trenches should be of a minimum 50mm^2 cross sectional area. (A possible source of this is recovered overhead line conductor.) The minimum strand diameter shall be 2mm to provide some resistance to corrosion.

These conductors shall be laid as single lengths. If the excavations radiate in diverse directions, buried copper conductor should be laid in each as far as practicable, up to 200m.

Care shall be taken to avoid running the additional conductor through fields with livestock.

(f) Where the substation is known to be Cold, the HV and LV Earthing Systems shall be combined permanently to form one Earthing System.

(g) If a Cold site cannot be achieved, the HV and LV systems must be kept separate; refer to the guidance in Section 5.6.

(h) If the substation perimeter fence is metallic, it shall be bonded to the earthing busbar only if the site is Cold. For Hot sites, the fence must be 2m or more from any equipment (i.e. cannot be touched at same time as earthed metalwork), and equipped with its own Earth Electrode system in a similar way to grid or primary substations.

If this separation is not practical, on a Hot site the fence may be bonded ONLY IF measures are taken to limit Touch Potential risk outside the fence. These measures include (and are not limited to) perimeter electrode, bonded to the fence, and insulating ground coverings outside the fence-line such as chippings, concrete, or asphalt (tarmac).

A metallic fence is not permissible for Type 1 designs, and must always be assessed according to Type 2 or 3 as appropriate.

(i) There is no strict requirement for metal substation door(s) and/or framework to be earthed. Ultimately the need or otherwise is subject to risk assessment, but the following rules of thumb apply:

- If site is Cold, metal doors should be bonded.
- If site is Hot, doors should be bonded only if they come within 2m of HV steelwork. It will then be necessary to ensure that horizontal grading electrode is buried 1m in front of the outermost point of the door open at 90 degrees, to manage Touch Potentials on the door.

- If site is Hot and doors are >2m from HV earthed metalwork (including RTUs, etc.), they should be earthed with 1.2m rods attached to both bottom corners of the metal doorframe. These serve little purpose other than to drain any stray induced current, but this is preferable to leaving the frame unbonded, where theoretically it may float to a potential above that of surrounding soil.

If luminaires / security systems etc. are wired to the metal doors, these systems shall be of class II insulated construction (unearthed), or connected via an isolation transformer unless the site is Cold and doors are bonded to a combined HV/LV system.

NOTE:

Each individual connection to the Earth bar or bars must be labelled. This is particularly important where a substation may have separate HV and LV Earth bars. In addition, if Bonding Conductors are not visible throughout their length, they should bear labels to indicate what they connect together. 'Traffolyte' or similar labels should be used for this purpose.

All the preferred arrangements use buried bare copper conductor to both act as a means of connection (e.g. between buried rods) and to function as an Earth Electrode. The minimum cross sectional area of buried copper conductor within the confines of a substation Earth loop conductor shall be 70 mm^2 unless otherwise stated. Refer to Appendix B for alternative sizes.

Where segregated HV and LV earthing is used (i.e. Hot sites), the LV Earthing Conductor must be insulated at the substation to ensure 9m separation (or otherwise as required according to Table B2) between HV and LV Earths. Care must be taken to ensure that this separation is maintained throughout the length of the additional buried conductor.

A2 Integral / Basement Substations

It is not normally practical to install a standard substation earthing layout in a building. In these situations a common approach shall be applied using earth rods installed through the substation floor or in the basement, with external electrodes underneath the HV cables, and an embedded mesh within the floor screed (to control the touch and step voltages). Connection to vertical piles, if possible, may be used to augment the earthing system.

It is not usually possible to separate the HV and LV earths, so it is important to achieve an EPR value of less than 430V (COLD site) so that HV and LV systems can be combined. If the EPR is greater than 430V or if the building or its electrical supply involves railways or other infrastructure, a bespoke design is usually necessary.

Substations in existing or new buildings shall be provided with a buried rebar mesh to control touch voltages in and around equipment to less than 10% of EPR. This shall be bonded to the main earthing system with duplicate and reliable bonds. For retrofit, a mesh can be buried in a shallow concrete screed (50mm), or in some cases a surface laid solution (e.g. checkerplate) can be acceptable, depending on civil requirements.

This touch voltage control is in addition to the substation electrode system. 2 or more dedicated copper bonds must leave the substation and connect to separate buried electrode or rods. These will usually be directly laid/driven in soil immediately below or adjacent to the substation room, but in the case of a substation above a basement or otherwise elevated, downleads shall connect the substation to electrodes using as short a route as possible. If it is not possible to install rods/electrodes immediately below the substation room, the electrodes can be offset, e.g. installed outside the building footprint, or with incoming cables etc. Note that care is required if these downleads can be touched outside the substation, since there will be no touch voltage control. If the substation is COLD this is less of a risk (since LV steelwork etc. will already be accessible), but if a HOT site is unavoidable, downleads / electrode connections MUST be insulated or capped to prevent danger and this must be considered as part of the bespoke design, together with measures to safely manage the interaction between HOT HV metalwork and nearby LV bonded metalwork / structural steelwork / pipework etc.

In integral and basement substations the resistance contribution from vertical steel piles may be used to supplement the main earthing system provided they are reliably connected, and the installed electrode system (without the piles) satisfies the surface area requirements described in this document. The resistance of vertical piles is included in a similar way to the network contribution when calculating EPR, i.e. can be assumed to appear in parallel with the substation electrode provided the piles are a reasonable distance from the substation rods.

NOTE:

If copper tape can be installed with vertical piles this can be included in surface area calculations, but steel piling rebar should not normally be included.

A3 Absolute Maximum Limits for Electrode Resistance

The Earth Electrode installation(s) shall have an Earth resistance not exceeding the following values. In most cases the designer will specify lower values, which must be achieved:

- 40Ω for all separate LV neutral Earth Electrodes (first or main LV electrode).
- 100Ω for additional ‘PME’ electrodes.
- 20Ω overall value for LV networks (all LV electrodes combined).
- 10Ω for 6.6kV and 11kV electrodes on ground mounted plant.
- 25Ω (for 6.6kV) and 40Ω for 11kV Earth Electrodes on pole mounted equipment (subject to the note below).

The values for the HV electrodes are chosen on the assumption that Earth Fault relays will not be set higher than 80A.

NOTE:

For pole-mounted equipment it is desirable to reduce to 25Ω for the HV Earth, in order to ensure reliable operation of Earth Fault relays. If this value cannot be achieved (and provided touch voltages are still acceptable), a value up to 40Ω is permissible provided that a protection clearance assessment (similar to that for Type 3 substations in Section 5.4.3) is carried out to confirm that protection operation will occur within 1 second. At 6.6kV, for the higher resistance electrodes, this may require an Earth Fault relay current setting of 50A or less at the controlling circuit breaker. Where surge arresters are fitted at a site (e.g. cable termination) then the preferred Earth resistance value is <=10Ω, if it can be achieved.

For ground mounted plant, the design rules of Section 5 still apply, and in many cases a value less than the permissible maximums above will be required to limit EPR and touch voltages.

Appendix B – Data Tables

B1 Ground Return Current I_{GR}% for Different (All Cable) Arrangements

Table B1 below gives indicative I_{GR}% for different cable types. The Electricity North West tool should be used to provide additional detail where substation resistances R_A and R_B are known to deviate significantly from the values listed below.

Table B1 – Ground Return Current Values for Typical Electricity North West 11kV Cables (based on a 0.11Ω source resistance R_A and 1Ω secondary resistance R_B)

CABLE TYPE/CABLE LENGTH (KM)	0.5	1	2	5	10
3 x 1c 300mm² XLPE (70mm² Cu wire sheaths)	4%	7%	10%	13%	13%
3 x 1c 185mm² XLPE (70mm² Cu wire sheaths)	4%	6%	10%	12%	13%
3 x 1c 95mm² XLPE (70mm² Cu wire sheaths)	7%	11%	17%	21%	22%
3 x 1c 300mm² XLPE EPR (35mm² Cu wire sheaths)	6%	11%	16%	21%	22%
3 x 1c 240mm² XLPE EPR (16mm² Cu wire sheaths)	13%	21%	31%	39%	43%
3 x 1c 185mm² XLPE EPR (35mm² Cu wire sheaths)	7%	12%	17%	21%	23%
3 x 1c 150mm² XLPE EPR (16mm² Cu wire sheaths)	13%	22%	31%	40%	43%
3 x 1c 95mm² XLPE EPR (35mm² Cu wire sheaths)	7%	12%	17%	21%	23%
3 x 1c 70mm² XLPE EPR (12mm² Cu wire sheaths)	17%	28%	39%	48%	52%
3c 185mm² XLPE (50mm² Cu wire sheath)	12%	21%	29%	38%	41%
3c 95mm² XLPE (35mm² Cu wire sheath)	13%	21%	30%	38%	41%
3c 300mm² PICAS	3%	5%	8%	10%	10%
3c 185mm² PICAS	4%	8%	11%	14%	15%
3c 95mm² PICAS	7%	12%	18%	22%	24%
3c 0.4 inch² PILCSWA	8%	14%	21%	27%	29%
3c 0.3 inch² PILCSWA	9%	16%	23%	29%	31%
3c 0.2 inch² PILCSWA	11%	18%	26%	33%	35%
3c 0.1 inch² PILCSWA	13%	22%	31%	38%	41%
3c 0.06 inch² PILCSWA	15%	25%	34%	43%	46%

B2 HV-LV Earth Separation Distances

Table B2 – Separation Distance (m) from Electricity North West Standard 3x3m Substations to 430V Contour

EPR(V)	1000	2000	3000	5000
SOIL				
UNIFORM SOIL	1.9	5.3	8.8	15.5
LO/HI 1:2	2.9	8.4	14	24.7
LO/HI 1:3	3.7	11	18.3	32.4
LO/HI 1:5	4.3	15.2	25.5	45.4
HI/LO 2:1	1.3	3.4	5.4	9.3

Hi/Lo 3:1	1.1	2.7	4.1	6.9
Hi/Lo 5:1	0.9	2.2	3.1	4.8

NOTE:

The soil models represent a top layer of 2m and a lower layer of infinite depth. Ratios refer to the soil resistivity of each layer, e.g. Hi/Lo 2:1 suggests top layer is 2x higher resistivity than lower layer.

These figures have been calculated for Electricity North West 3x3m substations, buried at 0.5m, with internal cross-members and corner rod electrodes (1.2m) and differ from standard distances given in e.g. ENA TS 41-24.

B3 Network Contribution

Table B3 – Maximum Theoretical (Minimum Resistance) Contribution in Dense Urban Areas

SOIL RESISTIVITY (ΩM)	EFFECTIVE AREA RADIUS (M)	MINIMUM EARTH IMPEDANCE (Ω)
10	<500	0.030
50	500	0.065
100	1000	0.100
300	1500	0.170
500	2000	0.230
1000	>2000	0.400

B4 Touch Voltage Limits

Touch and step voltage limits (U_T and U_S) are dependent on the shock duration and hence the total fault disconnection time including protection and circuit breaker operation. The additional foot contact impedance presented by different types of surface cover (soil, concrete, etc.) will also affect the limits.

The limits are set out in ENA TS 41-24 and summarised in Table B4 below for a range of clearance times and typical surface coverings.

Normal shoes may be assumed in operational areas. Barefoot scenarios are applicable for some situations; refer to Section B6.

Table B4 – Touch and Step Voltage Limits

PERMISSIBLE TOUCH POTENTIALS[A] (V)	PROTECTION CLEARANCE TIME										
	0.5	1	1.1	1.2	1.3	1.4	1.5	2	3	5	≥10[B]
BARE FEET (WITH CONTACT RESISTANCE) [A]	166	80	76	73	71	69	67	63	60	58	57
SHOES ON SOIL OR OUTDOOR CONCRETE	578	233	219	209	200	193	188	173	162	156	153
SHOES ON 75 MM CHIPPINGS	650	259	244	232	223	215	209	192	180	173	170
SHOES ON 150 MM CHIPPINGS OR DRY[C] CONCRETE	753	298	280	266	255	246	239	220	205	198	194
SHOES ON 100 MM ASPHALT	3600	1370	1300	1200	1100	1100	1080	990	922	885	866

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. Applicable in some situations outside substations. Not applicable within substation/operational areas.

B. The >= 10s 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 (>0.5 m) below ground level should be treated in the same way as soil.

B5 Step Voltage Limits

Limits for step voltage have been revised in national standards, and are now much higher than previously. As a result, compliance with touch voltage limits (above) will almost certainly provide acceptable step voltages in and around the substation, for individuals wearing footwear.

Care is needed if substations are located close to high risk areas (e.g. barefoot and/or wet locations such as swimming pools, paddling pools, schools/nurseries etc.), and such installations may require a bespoke design.

Proximity to livestock is perhaps the most common issue, since a relatively low voltage gradient (25V/m) around the substation can cause injuries or fibrillation in animals. Electrode should not be sited in areas frequented by horses or cattle, nor should it run close to pathways or gates. If such areas are unavoidable, the step voltage can be reduced by burying the electrode deeper or by insulating at key locations; however expert advice should be sought in such situations.

B6 Conductor Sizes

The conductor sizes that shall be used for different fault levels are provided in Table B5 below. 3 second duration allows the system to withstand slow (backup) protection operation. These figures allow a 250°C rise and are appropriate for bolted connections.

Electricity North West secondary substations generally require Earth Bonding Conductors to be sized according to the maximum Earth Fault Current that is foreseeable (typically 3kA for impedance earthed systems, this allows for some growth and ignores fault current decrement in 11kV feeder). It is not necessary to size for the higher phase-to-phase fault currents unless single phase equipment is present on the same site, or cross-country faults may be anticipated (see ENA TS 41-24).

Providing these conditions are met, 70mm^2 stranded conductor, or 25x3mm copper tape will be adequate in most situations, as shown in the Table B5 below. Note also there are additional requirements for electrode (buried bare conductor) as described below (Electrode Surface Area).

Table B5 – Approval Earth Conductors and Current Ratings (3s Duration)

	MAXIMUM CURRENT	
CONDUCTOR	**SINGLE CONNECTION**	**DUPLICATE CONNECTION**
70mm^2 Copper	7.1kA	11.8kA
95mm^2 Copper	9.6kA	16.1kA
25 x 3mm	7.6kA	12.7kA
25 x 4mm	10.2kA	16.9kA

NOTE:

For stranded conductors, the minimum strand diameter shall be 2mm; i.e. ‘flexible’ or ‘tri-rated’ conductor shall not be used below ground.

Electricity North West standard designs utilise a loop around the substation which is connected to an Earth stud or marshalling bar. The duplicate connection applies, therefore 70mm^2 stranded copper or 25x3mm tape is appropriate in most cases. The design fault level is the maximum Earth Fault level, not the smaller Ground Return Current since the electrode must remain intact for loss of network connection. Phase-to-phase fault current need not be considered at Electricity North West secondary substations.

B7 Electrode Surface Area

The minimum length of electrode to meet surface current density requirements is shown in Table B6 below. This ensures that soil/electrode interface remains stable under fault conditions.

Table B6 – Minimum Electrode Lengths per kA of Ground Return Current (3s Duration)

	SOIL RESISTIVITY					
Conductor	50Ωm	100Ωm	300Ωm	500Ωm	1000Ωm	3000Ωm
70mm² Copper	54m / kA	77m / kA	133m / kA	172m / kA	243m / kA	421m / kA
95mm² Copper	47m / kA	66m / kA	115m / kA	148m / kA	209m / kA	361m / kA

NOTE:

For a ground mounted system with I_{GR} = 0.25kA, in 100 Ωm soil, electrode length (including rods and perimeter ring) must exceed 0.25 x 77 = 19.25 metres.

The Ground Return Current I_{GR} may be used in this calculation, rather than absolute Earth Fault Current, provided there are duplicate network connections. In the absence of detailed calculation, I_{GR} may be assumed to be 1/3rd the Earth Fault Current for all-cable systems or refer to Section 5 & Appendix B1 for calculation methods.

ALL Electricity North West standard designs have a known (minimum) electrode surface area, and the acceptable Ground Return Current (in different soils) is shown in their relevant data tables. Where this figure does not exceed the Ground Return Current at site the electrode surface area must be increased accordingly using one of the options described in Section B9.

B8 Additional Electrode Options

Where it is necessary to reduce the earth resistance or to increase the electrode surface area the standard electrode designs may be augmented by the addition of:

(a) Longer rods

(b) Additional horizontal conductors

(c) Rod nests

These are described more fully below:

B8.1.1 Longer Rods

Standard rods may be extended up to 20m deep if necessary. In most soil structures, such lengths will only be possible if the hole can be augured (drilled) in advance, in which case it is usually necessary to back-fill the hole with bentonite or some other compound which can enhance (lower) the resistance value. Long rods are best when underlying soil is known to be low resistivity, or if the options are limited due to physical constraints. Refer to Table B7 below.

Table B7 – Earth Rod Resistance Versus Length for Different on Soil Resistivity Values

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

B8.1.2 Additional Horizontal Conductor or Buried Mesh

A single horizontal conductor buried in soil (at 0.5m or greater) can provide a low resistance connection with Earth. Generally its resistance will fall with increasing length, up to a point ‘the effective length’ beyond which no further benefit can be achieved. If it is possible to extend the electrode in 2 or more different directions, each electrode will provide a useful contribution. Electrodes that are close to each other, or radiate in similar directions, will not reduce the substation resistance significantly because their areas of influence overlap, and thus multiple electrodes will have a similar earth resistance to one.

Appendix F of ENA EREC S34 provides a table which gives the resistance of horizontal conductors against length, for different soil resistivity. Some values are also given in Table B8 below.

NOTE:

Care is required when electrode radiates from HOT sites since the size of the hot zone will be extended; this can cause issues if third party services or properties are inside this hot zone; refer to Sections 5.5.2 and 5.6 for further information. For segregated HV/LV systems, HV electrode should remain well clear of LV electrode/metallic sheathed cables and associated systems (such as street furniture).

It is possible to use preformed copper mats as electrode, and these can give other advantages as e.g. stance earths. They should be buried at least 0.5m below soil if they are to provide an electrode contribution, as shallower soil can dry in summer months. These are included in the table below.

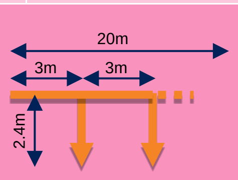
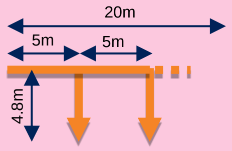
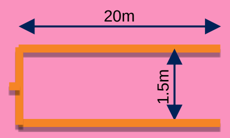
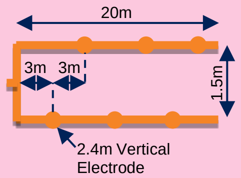
Other electrode arrangements (e.g. a wide mesh / zigzag or parallel conductors laid in a pavement) can provide a reduction in resistance where required, but may not be an optimal use of copper. A comparison of the resistance achieved by different arrangements is provided in Table B9.

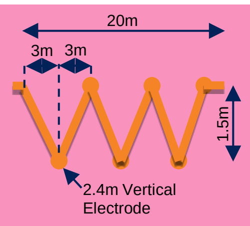
Table B8 – Horizontal Earth Conductor and Lattice Earth Mat Resistance for Different Soil Resistivity Values

CONDUCTOR/MAT LENGTH		RESISTANCE (Ω)							
		25Ωm	50Ωm	100Ωm	150Ωm	200Ωm	300Ωm	400Ωm	500Ωm
HORIZONTAL CONDUCTOR	10M	3.6	7.3	14.6	21.9	29.2	43.8	58.3	72.9
	25M	1.8	3.5	7.0	10.5	14.0	21.0	28.0	35.0
	50M	1.0	2.0	3.9	5.9	7.9	11.8	15.8	19.7
	100M	0.5	1.1	2.2	3.3	4.4	6.6	8.8	11.0
	150M	0.4	0.8	1.5	2.3	3.1	4.6	6.2	7.7
	200M	0.3	0.6	1.2	1.8	2.4	3.6	4.8	6.0
	250M	0.2	0.5	1.0	1.5	2.0	3.0	4.0	5.0
1M X 1M LATTICE MAT IN SOIL		13.2	26.3	52.6	79.0	105.3	157.9	210.6	263.2
1M X 1M LATTICE MAT IN EARTHING COMPOUND		3.7	7.3	14.7	22.0	29.3	44.0	58.6	73.3

Table B9 – Comparison of Different Electrode Options for a 20m x 1.5m Pavement Excavation

	Resistance (Ω)			
Arrangement	**50Ωm**	**100Ωm**	**300Ωm**	**500Ωm**
a	3.1	6.2	18.6	31.0
b	2.6	5.3	15.8	26.3
c	3.1	6.3	18.8	31.3
d	2.6	5.1	15.4	25.6
e	3.0	6.0	18.0	30.0

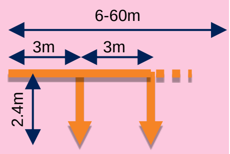
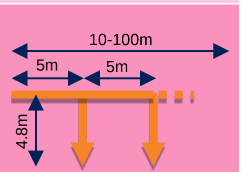
Arrangement (a) denotes	**Short Vertical and Horizontal Electrodes** Each short vertical electrode comprises of 1.2m rods coupled together to form the final vertical length e.g. 2.4m = 2 x 1.2m. The spacing between them is 3m and the total length of the arrangement is 20m thus there are 6 vertical electrodes in total. The top of each electrode shall be at a minimum depth of 0.5m below ground level.	
Arrangement (b) denotes	**Deep-driven Vertical and Horizontal Electrodes** Each deep-driven vertical electrode comprises of 1.2m rods coupled together to form the final vertical length e.g. 4.8m = 4 x 1.2m. The spacing between them is 5m and the total length of the arrangement is 20m thus there are 4 vertical electrodes in total. The top of each electrode shall be at a minimum depth of 0.5m below ground level.	
Arrangement (c) denotes	**Dual Horizontal Electrodes** Two 20m long horizontal electrodes installed in parallel with 1.5m spacing between them, i.e. each side of the pavement outside the substation. The top of each electrode shall be at a minimum depth of 0.5m below ground level.	
Arrangement (d) denotes	**Short Vertical and Dual Horizontal Electrodes** This arrangement is a mixture of arrangements (a) and (c) above. Two 20m long horizontal electrodes installed in parallel with 1.5m spacing between them, with additional short-vertical electrodes installed with 3m spacing between them on the horizontal axis, as shown. The top of each electrode shall be at a minimum depth of 0.5m below ground level.	

Arrangement (e) denotes	**Short Vertical and Zigzag Horizontal Electrodes** This arrangement is an alternative to arrangement (d) above. The vertical electrodes remain at the same positions but with interconnecting zigzag horizontal electrode instead of the two parallel horizontal electrodes. The spacing between the vertical electrodes is 3m on the horizontal axis and 1.5m on the vertical axis as shown. The top of each electrode shall be at a minimum depth of 0.5m below ground level.	

B8.1.3 Rod Nests

Rod nests are usually a combination of rods and horizontal conductor. The most effective contribution comes from rod/electrode which is outside the area of influence of neighbouring rods/electrode. Strings of rods ideally should be spaced so that each rod is 2xD from its neighbours, where D is the length of the rod, however due to space constraints a compromise if often required, and different ratios of depth to spacing can be used to good effect. Table B10 below provides some guidance in this regard but is not a definitive list.

Table B10 – Earth Resistance of Extended Horizontal Earth Electrode Arrangements with Rods

	RESISTANCE (Ω)							
# of Vertical Electrodes	**50Ωm**		**100Ωm**		**300Ωm**		**500Ωm**	
	(a)	**(b)**	**(a)**	**(b)**	**(a)**	**(b)**	**(a)**	**(b)**
2	7.2	4.4	14.5	8.8	43.4	26.3	72.3	43.8
4	4.4	2.6	8.7	5.3	26.2	15.8	43.6	26.3
6	3.2	1.9	6.4	3.9	19.3	11.6	32.2	19.4
10	1.3	1.3	2.6	2.6	7.9	7.9	13.1	13.1
20	1.3	0.8	2.5	1.5	7.6	4.6	12.7	7.6
Arrangement (a)	**Short Vertical and Horizontal Electrodes** Each short vertical electrode comprises of 1.2m rods coupled together to form the final vertical length e.g. 2.4m = 2 x 1.2m. The spacing between them is 3m and the total length of the arrangement depends on the total number of vertical electrodes. The top of each electrode shall be at a minimum depth of 0.5m below ground level.							
Arrangement (b)	**Deep-driven Vertical and Horizontal Electrodes** Each deep-driven vertical electrode comprises of 1.2m rods coupled together to form the final vertical length e.g. 4.8m = 4 x 1.2m. The spacing between them is 5m and the total length of the arrangement depends on the total number of vertical electrodes. The top of each electrode shall be at a minimum depth of 0.5m below ground level.							

B8.1.4 Piles

Building piles can be used as a contribution but should not be the sole means of providing an electrode. There shall be enough copper electrode to satisfy the surface density requirements before piles are considered. This is because, in extreme cases, piles can overheat and split under HV fault conditions.

If possible, copper tape can be driven with vertical piles, or installed before concrete is poured, to provide a valuable electrode, which may be treated (electrically) in the same way as a long vertical rod. Further information is available in ENATS 41-24.

B9 Protection Calculations

Table B10 – Protection Operation Time

PROTECTION CHARACTERISTIC	PROTECTION OPERATION TIME	
Instantaneous (INST)	0 (delay) + 10ms for oil, 5ms for vacuum (mechanical time)	
Definite Time (DT)	The specified operating time + mechanical time as above	
IDMT SI	$\frac{0.14}{\left(I_f/I_s\right)^{0.02}-1} \times tm$	where: I_f = Earth Fault Current (A) I_s = Earth Fault Current setting (A) tm = Earth Fault time setting The protection settings are available from the Protection Database Mechanical operating time needs to be added to obtain overall fault duration. Use 1 second (overall) in absence of detailed information.
IDMT EI	$\frac{80}{\left(I_f/I_s\right)^{2}-1} \times tm$	
IDMT VI	$\frac{13.5}{\left(I_f/I_s\right)-1} \times tm$	

Appendix C – Special Cases

C1 Secondary Substations Near, or Providing Supplies to, an Electricity Transmission Tower

Special care must be taken when providing an electricity supply to equipment mounted on a transmission tower, e.g. mobile phone transmitter, aircraft warning lights, etc. Further guidance is available in CP215 (Supplies to Mobile Phone Base Stations with Antennae on High Voltage Structures) and ENA ER G78.

Where practicable, secondary substations (and their Earth Electrodes) should not be installed within 50m of a transmission tower. Where this is unavoidable an earthing specialist or suitably qualified person should be consulted who must assess the EPR during a fault on the tower and the associated transfer potential impact on the secondary substation.

C2 Secondary Substations in High-Risk Locations

Where possible secondary substations should 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 C4).

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. Alternatively, the customer may be able to confirm the risk can be managed, for example fencing off an area of field to prevent livestock accessing land with high step potential.

C3 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 an Electricity North West earthing specialist / 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 ENA ER P24 and 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. Ideally they should be tested/inspected to ensure they are not subject to accelerated corrosion. This inspection could be done during any other works that exposes the cables, for example a new connection or diversion.

C4 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.

C5 Lightning Protection Systems

Lightning protection design is covered in BS EN 62305 and 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 a suitably qualified person.

C6 Non-Standard Arrangements

If a ground-mounted substation is to use an earthing layout other than a standard design, the design must be assessed using computer software to determine the touch voltages as a percentage of EPR, and appropriate Target Resistance values calculated.

C7 HV Metered Supplies

Electricity North West is not responsible for substations beyond its ownership but has a duty of care to ensure that the customer's system will not become hazardous during a fault. The Electricity North West and Customer Earthing Systems are often physically close to each other and the effect of one on the other cannot be overlooked. As such Electricity North West shall liaise with the customer and make available such information to ensure a safe overall design.

Interconnection of the two HV Earthing Systems is the preferred (and usually simplest) option unless the alternative (deliberate segregation) can be justified, i.e. is necessary for safety.

In practice, 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 ENWL. 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.

Where practicable the Electricity North West and Customer HV Earthing Systems should be designed to meet the requirements for safety independently of each other (the customer may assume normal network/sheath connectivity provided reliable and duplicate connections have been achieved). If this is satisfied then they may be connected together via two designated connections (>=70mm^2 copper or equivalent for impedance earthed systems) that are duly labelled. Note that if the combined Earthing System is Hot then the associated precautions must be applied to both the Electricity North West and Customer sites, e.g. segregation of LV Earth at the customer substation, care over transfer voltage onto other metallic services, etc.

NOTE:

ENWL 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.

Where it is not practicable to achieve the requirements for safety from the Electricity North West electrode, the substation may rely on the Customer's earthing installation providing that it is constructed to a similar standard to Electricity North West requirements and precautions are taken to prevent its disconnection. If the Customer earthing is modified or removed in future the earthing safety of the Electricity North West substation shall be reviewed. It is recommended that the links between the two substations are tested at regular intervals and the readings logged so that deterioration can be noted.

The situation can be more complex if the EPR exceeds 430V. In the simplest form, the ENWL/Customer substation earths may be connected together to form a single HOT site (or two disparate HOT sites with a HOT electrode corridor between them, depending on physical spacing). The customer must then ensure the LV earth (and everything connected to it) is spaced well clear of this HOT zone in the usual way (i.e. by applying a spacing of 9m or more from the HV metalwork/electrode). Care is needed when LV supplies are taken into the substation(s), and isolation transformers and class II equipment (plastic conduits, light fittings, switches etc.) should be used in the normal way (see 5.5.2).

Care is needed where metering multicores, LV supplies, control wiring or emergency trip button wiring extends from a HOT substation, since invariably its cores will be referenced (connected) to the HV earth and will therefore introduce a hazard outside the controlled touch potential areas. Such wiring should be insulated throughout its length, and ideally unarmoured (or if armoured, well covered and held clear of LV metalwork with insulating clips). It should terminate in plastic boxes / metering display units that do have metal components/controls so that no hazard will exist in normal circumstances. A small risk will be present if these boxes are opened (e.g. by meter reader etc), so suitable labels shall be affixed warning of the need for PPE etc. as appropriate to minimise risk. If manufacturers offer an isolation transformer or other galvanic isolation unit (e.g. optical fibre), this should be considered.

Under no circumstances shall armoured cables be terminated in the 'conventional way' using metal glands and metal boxes at each end, as such measures could easily interconnect HV and LV earthing systems and/or introduce significant risk under fault conditions.

If a COLD site cannot be achieved, or if a conventional HOT design as described above is not workable, the following design options shall be considered:

- Increase electrode to make the site COLD, and/or explore options for using piles or abandoned lead sheathed cables as supplementary electrode; or:
- Interconnect the HV and LV earths and operate with the necessary measures in place for a HOT combined HV/LV system. This is a rare situation and 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. The system will be compromised if a remote reference (e.g. other LV service, phone wire, cable TV, Ethernet cable, metal pipe etc.) is introduced to the HOT area. A suitably qualified person should be involved to carry out or commission a bespoke design in such situations. Or:
- Segregate the ENWL 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

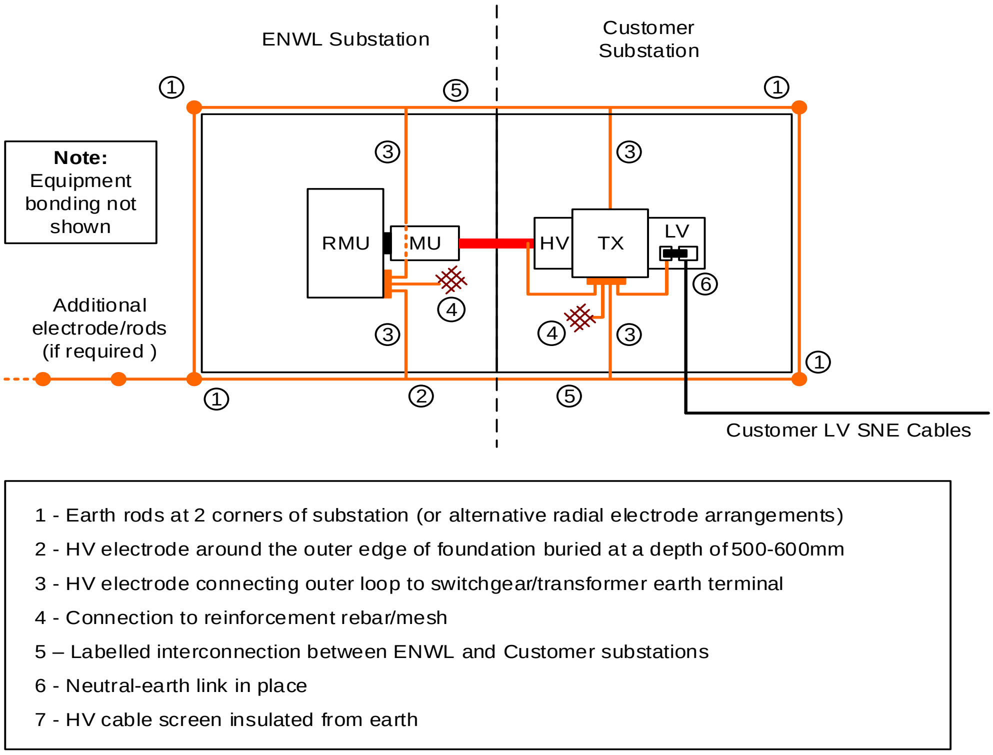
of a span of unearthed overhead line or cable sheath insulation joints between the site and ENWL's system (e.g. similar to that outlined in ENA EREC G78 for mobile phone masts). However the working practices (such as isolation and earthing for work on the HV system) need careful consideration in this situation.

NOTE:

In addition, any EPR greater than 430V requires special consideration if there are metallic boundary fences or metallic buildings in the vicinity.

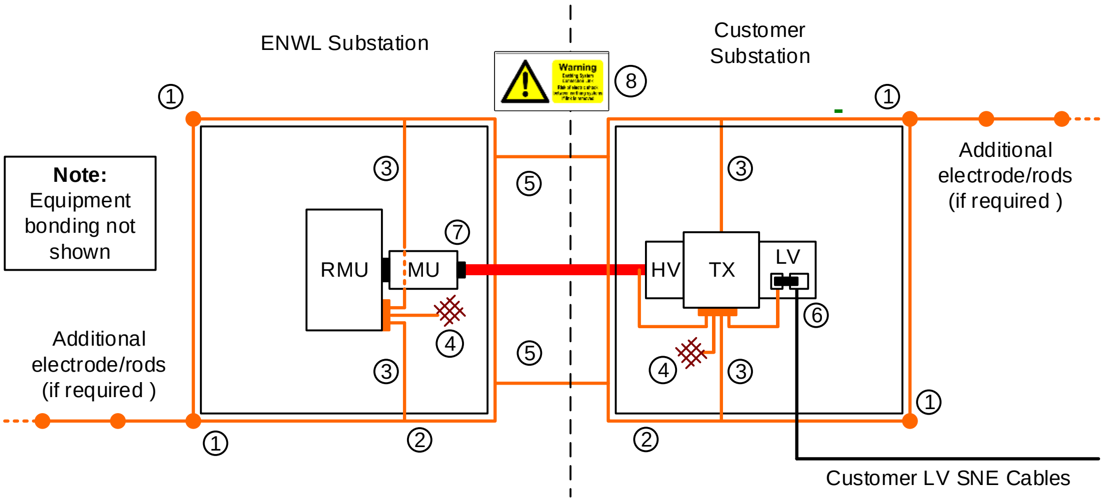
The figures below give some guidance related to various arrangements:

Figure C1 – COLD Supply to Customer Site, Shared Building



[Single combined building shown, alternatively separate ENWL and customer substations may be interconnected in same way, with each using a full perimeter electrode as shown:]

Figure C2 – COLD Supply to Customer Site, Separate Buildings



1 - Earth rods/electrodes at 2 corners of substation (can be installed internally)

2 - HV electrode around the outer edge of foundation buried at a depth of 500-600mm

3 - HV electrode connecting outer loop to switchgear/transformer earth terminal

4 - Connection to reinforcement rebar/mesh

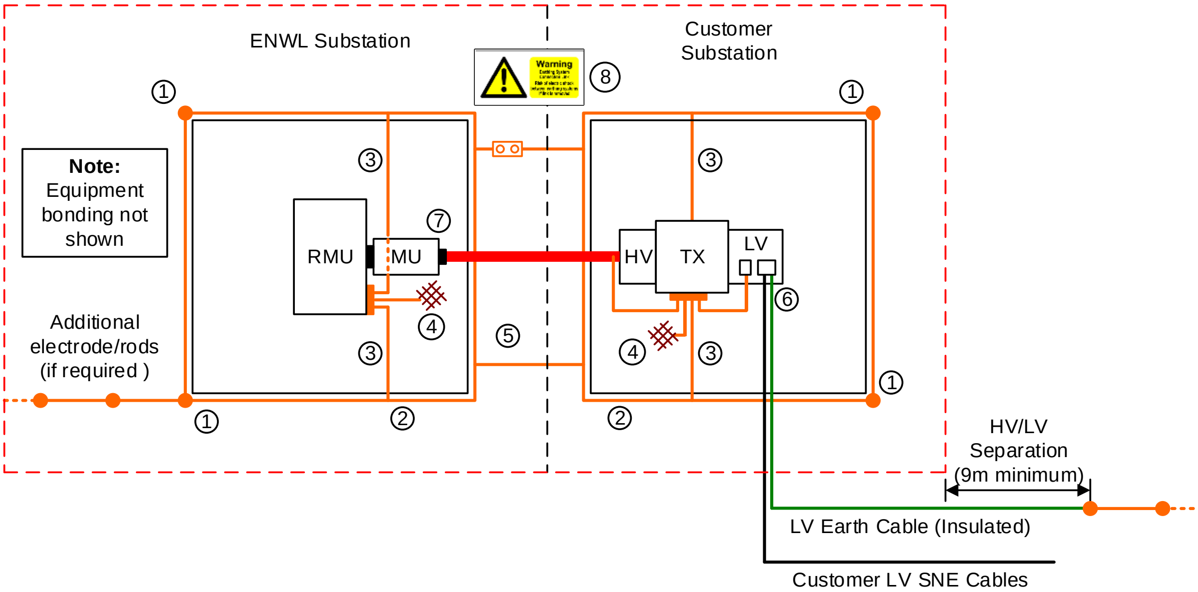
5 - Interconnection via a labelled link between substations

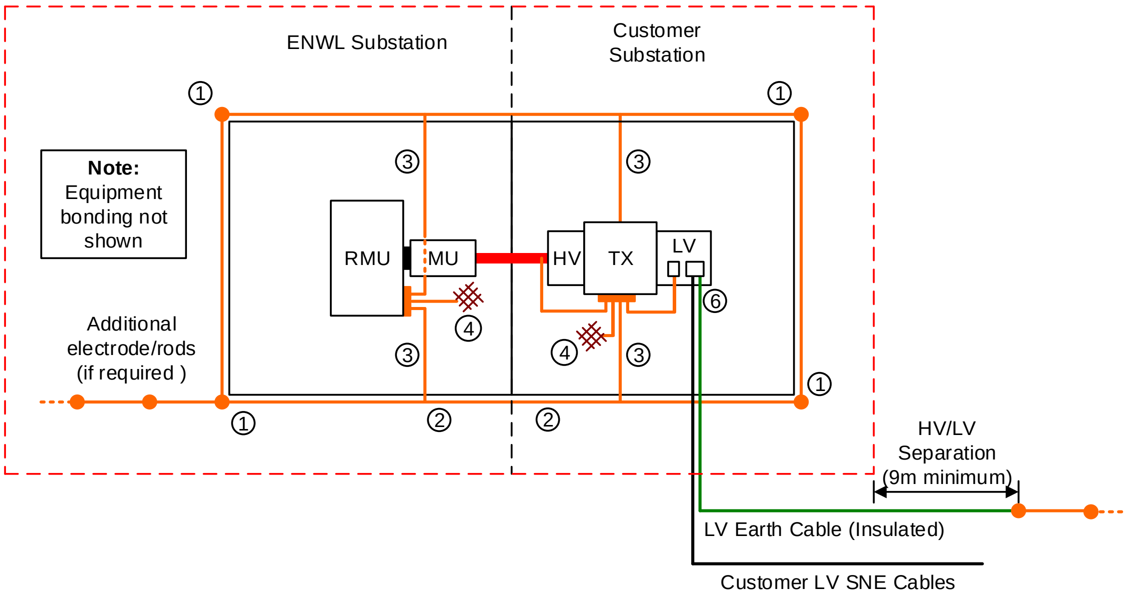
6 - Neutral-earth link in place

7 - HV cable screen unterminated or with provision to disconnect for testing

8 - Warning labels – do not disconnect

Figure C3 – ENW and Customer Substations (HOT Sites)





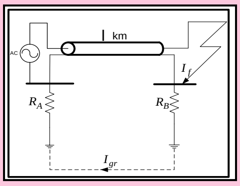
1 - Earth rods/electrodes at 2 corners of substation (or installed internally)
2 - HV electrode around the outer edge of foundation buried at a depth of 500-600mm
3 - HV electrode connecting outer loop to switchgear/transformer earth terminal
4 - Connection to reinforcement rebar/mesh
5 – Labelled (bolted) connection between ENWL and Customer substations
6 - Neutral-earth link removed
7 - HV cable screen unterminated/insulated gland, or via bolted link to facilitate testing
8 - Warning labels

Appendix D – Worked Samples

D1 Worked Example 1 – Ground Mounted Substation, Urban Area

In this example, a new substation is to be installed in an existing urban area. The details are summarised in Table D1 below:

Table D1 – Available Information

		COMMENTS
Earth Fault level (at primary busbars)	2kA (11kV Earth Fault Current, two transformer primary)	Designer can use e/f level at POC if known. For initial Type 1 (or 2) assessment, network modelling not required (unless Hot).
Feeding arrangement	 All-cable	All-cable means that only a small fraction of e/f current flows in the soil, this is least onerous for earthing design.
Alternative arrangements	NOP from same primary	Need to consider alternative running arrangements if e/f levels or sheath/Ground Return Current splits are likely to be significantly different.
Existing network	>3km radius, 1960s lead sheathed cables	= large area electrode, i.e. a low resistance to Earth.
Source substation details	R_A = 0.12Ω, EPR = 340V, ρ (soil res.) = 240Ω.m	Electricity North West earthing database. Soil resistivity may also be found from online sources.

First – carry out the test for GES networks:

Ground mounted……………………………………..............	☑
All-cable fed …………………………………………….	☑
Part of a large (>1km radius) urban network ………………...	☑
Local average soil resistivity 300Ω.m or better …………	☑
Impedance earthed source substation (max. 2kA Earth Fault Current). ……………………………………	☑
Cold source substation with resistance < 0.17Ω (or measured Network Contribution < 0.17Ω)‡ ………………	☑
Standard Electricity North West substations without metal fences / enclosures, in GRP or integral substations with Touch% <= 10%...	☑

… the substation passes all the tests for Global Earthing System (Type 1), and a standard GRP or Brick/Integral substation can be installed, with HV and LV Earth-link in place, providing that a 10Ω electrode can be achieved and that:

- Re-bar bonding or perimeter electrode can be installed as per standard designs, and
- Connections to the wider network are secure, reliable and duplicated (via HV and/or LV cable sheaths).

These measures are critical to the ongoing safety of the site.

In summary:

- This installation is a standard 'Cold' site suitable for use in dense urban areas with existing lead-sheathed networks. The majority of installations in cities or large towns will fall into this category.

D2 Worked Example 2 – Ground Mounted Substation, Rural Area

In this example, a new substation is to be installed in a rural area fed from an overhead line. This situation is much more onerous than Example 1 due to a) higher Ground Return Current %, and b) less Network Contribution.

The substation immediately fails the tests for Type 1 and therefore the designer should begin with a Type 2 assessment. This initially requires gathering of relevant data as shown in the tables below.

Table D2 – Available Information

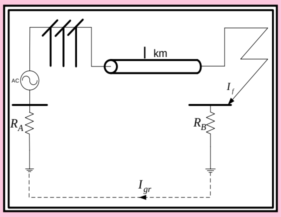
		COMMENTS
Earth Fault level	3kA at primary (3 TX impedance earthed), 600A at POC	E/f level at POC limited only by zero sequence impedance of circuit as default in modelling tools. In practice where R_B is high (small or no network) this will further limit current and may be considered for design economy.
Feeding arrangement	 Cable-line-cable or line-cable	For any OHL, assume 100% of e/f current flows via ground. This is worst case assumption but adequate for design purposes. Simplified equivalent diagram shown.
Distance from primary	3km	Influences the e/f level and sheath-return current – less relevant here because fault level at POC is known and overhead line is present.
Alternative arrangements	NOP from other primary	Not considered in this example – similar fault level and arrangements.
Existing network	None	Worst-case scenario, nothing in parallel with substation electrode system.
Protection setting	Inst E/F 80A	Assume will operate < 1 second for any Earth Fault into a 10Ω electrode.
Soil resistivity	See below (source sub)	Can be found from online sources (unless Hot).
Source substation details	RA = 0.17Ω, EPR = 340V, ρ (soil res.) = 240Ω.m	Electricity North West earthing database.

Table D3 – Assumptions / Calculations

		COMMENTS
Ground Return Current %	100% = 600A	No calculation required for OHL.
Protection clearance time	<1 sec	Not calculated; actual clearance time may be faster and can be used if 1 sec is problematic.
Permissible touch voltage	233V	On soil, normal footwear, 1 second.
Arrangement parameters:	E.g. Any design with touch% = 10% Resistance = (say) 19Ω (in 240Ω.m)	Appendix A. Resistance scaled with soil resistivity.
Network Contribution	None – standalone	Appendix B.
EPR design limit (SAFE)	1165V is max permissible whilst ensuring touch voltages are acceptable (i.e. 1165 x 20% = 233)	2kV (max permissible) does not achieve safety but might be permissible if a design with lower I_{GR}% is used.
EPR calculation (no Network Contribution)	EPR = 600A x R_B So R_B = 1165/600 = 1.94Ω (SAFE, without Network Contribution)	This is maximum local electrode resistance that is acceptable. The sub gives 19Ω so additional 2.1Ω electrode is required – refer to Appendix B to see how this can be achieved; around 250m of horizontal conductor may be required (or 2 or more shorter lengths, or rod nests etc.).
EPR with Network Contribution	Same as above (1165V), no contribution. Site is Hot.	
Resistance needed to achieve Cold site:	= 430/600 = 0.72Ω.	Gives max 86V touch voltage in normal service (20% of 430). Expense of electrode required may not be justified if Hot site acceptable.

In summary:

- This design requires a local overall electrode resistance of 1.94Ω to ensure safe Touch Potentials and will then be SAFE and Hot.
- The site could be made Cold by installing electrode to achieve 0.72Ω. The designer needs to decide if this is practicable and/or necessary. If for example, a small ground mounted network exists with bonded HV/LV, it is seldom practical to insert a Hot substation into it.

- If the installation is still problematic, a Type 3 assessment could explore further design economies, for example the additional impedance of the electrode system will reduce fault current, and the resultant current could be used in EPR calculations. Such an approach will involve a degree of iteration (altering overall R and calculating EPR) to converge on the optimal solution.

D3 Worked Example 3 – Town Network

This example doesn't qualify for GES/Type 1 due to larger current and smaller network and requires a Type 2 assessment. In this case, the design is acceptable, but if problematic then a Type 3 assessment would be justified.

Table D4 – Data for Worked Example 3

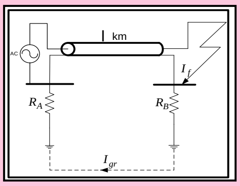
		COMMENTS
Earth Fault level (at primary busbars)	3kA (11kV Earth Fault Current, three transformer primary)	e/f level at POC not known.
Feeding arrangement	 All-cable	New triplex cables looped from network.
Alternative arrangements	None	Need to consider alternative running.
Existing network	500m radius, 1960s lead sheathed cables	
Source substation details / soil	R_A = 0.12Ω, EPR = 340V, ρ (soil res.) = 400Ω.m	Electricity North West earthing database. Soil resistivity may also be found from online sources.
New substation	Unit substation, dry concrete (indoor/undercover) around equipment. 20% max. touch voltage	

Table D5 – Calculations

		COMMENTS
Ground Return Current %	20% = 600A	Calculated from S34; 20% is valid estimate for short cable runs using standard triplex cables. Electricity North West tool will give better accuracy.
Protection clearance time	<1 sec	Not calculated; actual clearance time may be faster and can be used if 1 sec is problematic.
Permissible touch voltage	296 V	On concrete, normal footwear.
Arrangement parameters:	Touch% = 20	Appendix A.
Network Contribution	0.8Ω	An estimate based on tables in Appendix B and applicable to sparse network (Electricity North West's database for primary substation, if connected to same cable network, will provide indicative figure, or a measurement should be commissioned if there is doubt).
EPR design limit (SAFE)	1480V is max permissible whilst ensuring touch voltages are acceptable (i.e. 1480 x 20% = 296)	2kV (max permissible) does not achieve safety.
EPR calculation (no Network Contribution)	EPR = 600A x R_B So R_B = 1480/600 = 2.47Ω.	Requires 2.47Ω to make SAFE, without Network Contribution.
EPR with Network Contribution	=600 x (0.8 // 2.47) = 362V	Site becomes Cold with Network Contribution.

In summary:

- This design requires a local electrode resistance of 2.47Ω to ensure safe Touch Potentials when Network Contribution is disregarded. When the system is tied to the local network (via normal cable sheath connections), the EPR drops to less than 430 volts, and is thus SAFE and Cold, assuming
  - No exposed metalwork connected to the HV earth
  - No metal fences within 2 metres
- It will be necessary to install additional electrode to reduce the substation electrode resistance to 2.47Ω. Referring to Table B6, for 600A of ground return current, a minimum length of 172m x 0.6kA = 103m will be required to meet current density requirements. (The nearest quoted value of soil resistivity (500Ωm) has been used).

Appendix E – Measurement Methods

E1 General

This section provides an overview of the measurement techniques required at design, commissioning or during maintenance of a secondary substation. More detail may be found in BS 50522 and BS 7430.

E2 Safety

The earthing related measurements described in this section are potentially hazardous. They must be carried out by competent staff using safe procedures following a thorough assessment of the risks. The risk assessment should include, but not be limited to, consideration of the following aspects and the necessary control measures implemented as necessary, e.g. personal protective equipment, special procedures or other operational controls.

(a) Potential differences that may occur during Earth Fault conditions between the substation Earthing System and test leads connected to remote test probes. The likelihood of an Earth Fault occurring should be part of this assessment, e.g. not allowing testing to proceed during lightning conditions or planned switching operations.

(b) Potential differences that may occur between different Earthing Systems or different parts of the same Earthing System. In particular, approved safe methods must be used when disconnecting Earth Electrodes for testing and making or breaking any connections to Earth conductors which have not been proven to be effectively connected to Earth.

(c) Potential differences occurring as a result of induced voltage across test leads which are in parallel with a High Voltage overhead line or underground cable.

(d) Environmental hazards of working in a live substation or a construction site as governed by the Distribution Safety Rules or the Construction (Design and Management) Regulations as applicable.

(e) Injury due to striking a buried service when inserting test spikes into the ground.

(f) Injury when running out test leads for large distances in surrounding land.

E3 Instrumentation and Equipment

Only approved Electricity North West test equipment shall be used (refer to CP684). Each test instrument must have a current calibration certificate, have been regularly serviced and be in good working order with a charged battery.

E4 Soil Resistivity Measurements

For Type 1 designs in urban areas, the soil resistivity may be obtained from Electricity North West database or geological mapping. Site specific soil resistivity measurements are required for Type 3 designs where detailed analysis is required and also for Type 2 designs which are Hot.

Where site specific measurements are required the Wenner Method shall be used as described below.

E4.1 Method

A four-terminal Earth tester is used for these measurements and a typical test arrangement is shown in Fig. E1. An array of four small probes inserted into the surface of the soil are used to circulate current and measure the resulting potentials at specified points. Using Ohm's law a resistance can be calculated which may be related to the apparent resistivity at a particular depth using suitable formulae. Varying the positions of the probes, and hence forcing the current to flow along different paths, allows the apparent resistivity at different depths to be measured. In the Wenner Array an equal distance is maintained between each probe and this is called the Wenner Spacing.

For secondary substations the following Wenner Spacings are recommended:

1m	1.5m	2m	3m	4.5m	6m	9m	13.5m	18m	27m

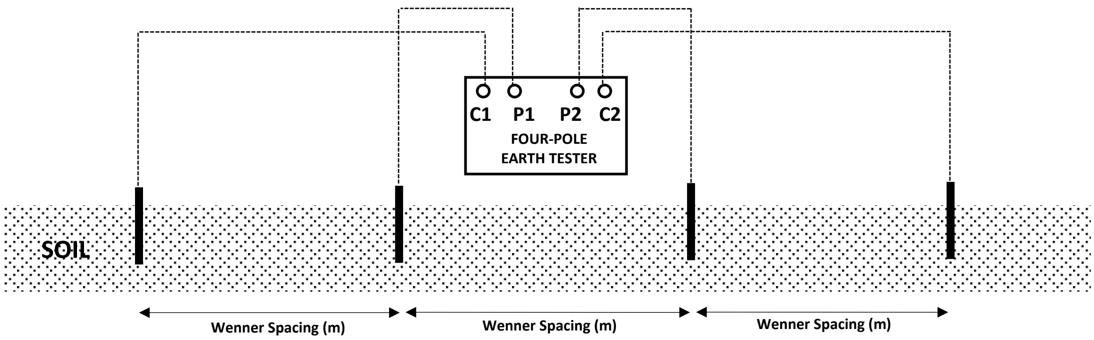
This requires two test leads of 40.5m length and two of 13.5m length. Sufficient space is required to run out leads along the ground in a straight line for 81m. The ground must be soft to allow insertion of test probes. If there is insufficient space a shorter route may be used with measurements taken to the maximum spacing possible up to 27m. A minimum of two soundings should be taken, in different locations near to the substation.

In urban areas meaningful measurements may only be obtained from the nearest parks or open ground and so results from several locations around the substation are essential so that an average can be made.

Measurements should be taken away from any buried metallic services / structures or any sources of stray DC, e.g. electrified tramways.

Measurement of low soil resistivity will require instrumentation with a 1mΩ resolution.

Fig. E1 – Soil Resistivity Measurement using the Wenner Array



E4.2 Interpretation of Results

The results shall be interpreted by an Electricity North West suitably qualified person using approved software.

Knowledge of the soil resistivity at different depths is important when designing the most effective electrode to reduce the substation Earth resistance. For example, vertical rods are better suited to a soil with a high resistivity surface layer and low resistivity material beneath. Conversely, where there is low resistivity material at the surface with underlying rock then extended horizontal electrodes will be more effective.

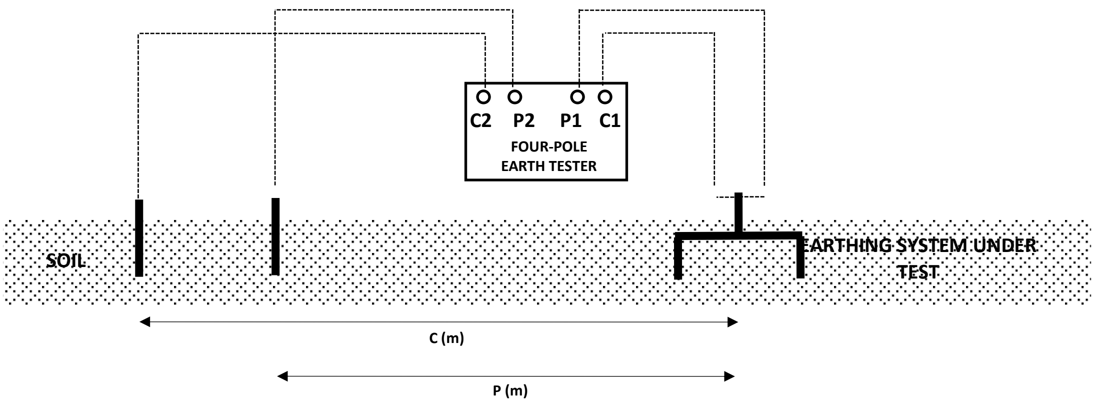
E5 Earth Resistance Measurements using the Fall-of-Potential Method

The fall-of-potential method can be used to measure the substation Earth resistance where practicable on commissioning of a new substation and subsequently at maintenance intervals. The measurement will include all earthing components connected at the time of the test.

E5.1 Method

The fall-of-potential method uses a temporary current electrode installed in the ground a distance, C, from the Earthing System under test and a potential electrode a distance P, as shown in Fig. E2. An approved four-pole Earth tester is used to inject a small test current into the Earth Electrode and returned via a remote probe. A voltage gradient is set up around the electrode and a second probe is used to measure this with respect to the electrode potential. The resistance is calculated by the test instrument and results are normally presented as a curve of resistance versus distance from the substation along a particular route. The potential is normally measured in a straight line between the test electrode and the current electrode. Recommended distances for C and P are provided in Table E1 together with guidance on how to interpret the results.

Fig. E2 – Earth Resistance Measurement using the Fall-of-Potential



In urban or industrial areas it may not be possible to use the fall-of-potential if no suitable routes exists for the test lead / probe set up. Alternative methods must be used in these locations as described in Section E6.

The current and voltage probes should not be located near to buried metallic services or structures. The route selected should ideally be in the opposite direction to any known metallic services or extended Earth Electrodes, or as a minimum have 45° separation from it.

Table E1 – Recommended Fall-of-Potential C and P Distances and Interpretation

ELECTRODE UNDER TEST	DISTANCE C	DISTANCE P	INTERPRETATION OF ELECTRODE EARTH RESISTANCE
Standard secondary substation electrode, loop with rods	30m	15m, 18m, 21m	18m reading to be used providing 15m reading is lower and within 10%, 21m reading is higher and within 10%.
Standard electrode plus additional electrode up to 20m radially.	100m	50m, 60m, 70m	60m reading to be used providing 50m reading is lower and within 10% and 70m reading is higher and within 10%.
Standard electrode plus additional electrode up to 50m radially.	200m	100m, 120m, 140m	120m reading to be used providing 100m reading is lower and within 10% and 140m reading is higher and within 10%.
Electrodes larger than 50m or underground cable networks.	400m	80m, 120m, 160m, 200m, 240m, 280m, 320m.	Interpretation by an Electricity North West suitably qualified person.

NOTE:

That use of shorter C distances than above will normally result in an overstated (higher than actual) Earth resistance.

If a three-pole Earth tester is used the resistance of the lead connecting to the electrode under test will add to the result and must be corrected for.

E6 Comparative Method of Measuring Earth Resistance

This method is useful to measure the Earth resistance of a relatively small electrode with reference to a larger interconnected Earthing System. It can be used to measure a secondary substation electrode in an urban environment where it is not possible to use the fall-of-potential method, providing there is access to a reference Earth, e.g. the existing Electricity North West HV or LV earthing network.

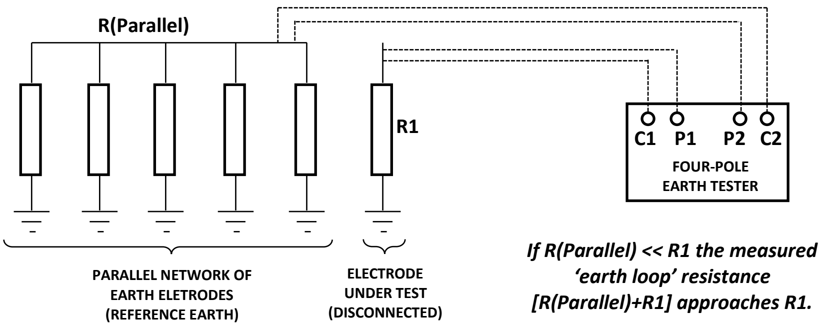
This method cannot be used to measure overall Earth resistance once all components are connected together, only the fall-of-potential is suitable for this.

The two derivatives of the comparative method are described below.

E6.1 Comparative Method – Electrode Disconnected from Reference Earth

The method is illustrated in Fig. E3, and requires that the electrode being tested is disconnected from the reference Earthing System, e.g. immediately after installation of the substation electrode prior to connecting of any cable sheaths. A standard four-pole Earth tester may be used with terminals C1 and P1 connected to the electrode component being tested. Terminals C2 and P2 are connected to the reference Earth. Current is circulated around the Earth loop containing the electrode and the reference Earth resistances and the voltage developed across them is measured. Using Ohm's Law the series 'loop resistance' is calculated. If the reference Earth resistance is sufficiently low relative to the electrode resistance the measured value will approach the electrode resistance.

Fig. E3 – Illustration of Earth Resistance Measurement using the Comparative Method and a Four-Pole Earth Tester (Test Electrode Disconnected)



Typical reference Earths are listed in Table E2.

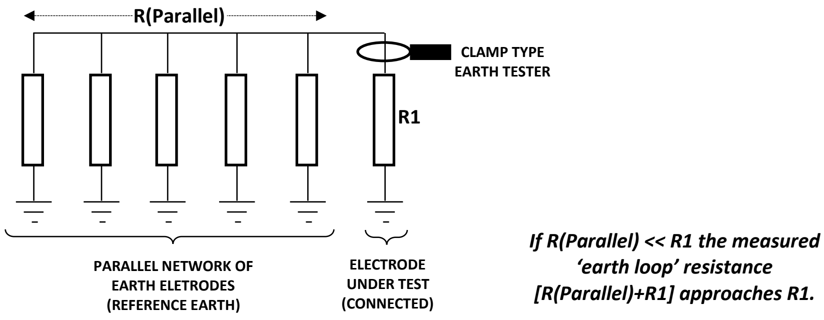
Table E2 – Examples of Reference Earths to be used with Comparative Method

ELECTRICITY NORTH WEST LV EARTHING SYSTEM	ELECTRICITY NORTH WEST HV EARTHING SYSTEM	OTHER
The Earth terminal in a nearby street light or other street furniture.	HV cable sheaths if connected at the other end.	A lightning protection system.
The LV neutral Earth associated with a PME network, e.g. via a mains socket in a nearby premises.	A nearby HV substation Earthing System.	A large steel frame building or other large metallic structure such as a bridge.

E6.2 Comparative Method – Electrode Connected to Reference Earth

This method, illustrated in Fig. E4 uses a similar principle but requires the electrode being tested to be connected to the reference Earth via a single connection. A clamp type meter is placed around the connection to the electrode which generates and measures current and voltage in the electrode loop and displays the 'loop resistance'. The most common application for this method is to measure the substation electrode resistance after connection of the HV cable screens, the latter providing the reference Earth. An advantage of this method is that, when the substation is in service, the local Earth Electrode may be tested without disconnection reducing safety risks. Facilities are included in the standard designs to allow testing of the substation electrode with a clamp meter.

Fig. E4 – Illustration of Earth Resistance Measurement using the Comparative Method and a Clamp Type Resistance Meter (Test Electrode Connected)



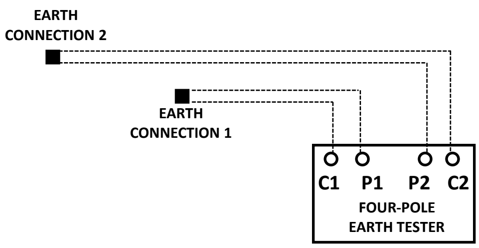
E7 Earth Connection Resistance Measurements (Equipment Bonding Tests)

This technique is used to measure the resistance between a plant item and the main substation Earth Electrode to check bonding adequacy. This is useful during commissioning of a new substation to confirm that each item of plant is effectively connected to the Earth Electrode system. It is also useful as an on-going maintenance check and for operational procedures, e.g. post-theft surveys.

E7.1 Method

A micro-ohmmeter is used to measure the resistance between two points and the connection arrangement is illustrated in Fig. E5.

Fig. E5 – Connections for Earth Bonding Conductor Resistance Measurements



For measurements between points that are no more than 10m apart the measured resistance should not exceed 20mΩ. Resistances higher than this must be investigated as it may indicate a bad joint or a disconnected Earth conductor.

E8 Earth Conductor Joint Resistance Measurements

This test is used to measure the resistance across an Earth conductor joint to check its electrical integrity. This is normally performed for every joint created at a new substation prior to backfilling. It is also carried out during periodic maintenance assessments.

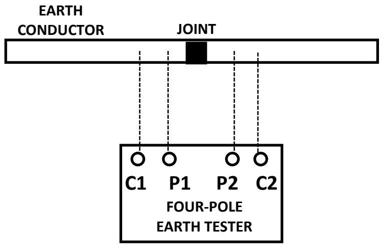
E8.1 Method

This method uses a micro-ohmmeter to measure electrical resistance and is suitable for bolted, brazed and welded joints. It does not check the mechanical integrity of welds or for voids inside a joint.

Most micro-ohmmeters are supplied with standard leads with two sharp pins that can penetrate through paint or surface corrosion to reach the metal underneath. The first set of leads is connected to one side of the joint and the second set to the other as illustrated in Fig. E6. Ideally, the connectors should be no more than 25mm either side of the joint. A suitable scale must be selected on the instrument (normally a minimum current of 10A is required to measure in the micro-Ohm range) and an average value recorded after the test polarity has been reversed.

Joints must also be mechanically robust and survive a firm tap with a steel hammer.

Fig. E6 – Connections for Earth Conductor Joint Resistance Measurements



The measured resistance should not significantly exceed that of an equivalent length of conductor without a joint. Joints which exceed this by more than 50% must be remade.

E9 Earth Electrode Separation Test

This technique can be used to assess the electrical separation of two electrodes in the soil by measurement, e.g. segregated HV and LV electrodes at a secondary distribution substation.

E9.1 Method

This method requires that the Earth resistances of the two electrodes (R_1 and R_2) have been measured separately using the fall-of-potential method described in Section E5 or the Comparative Method described in Section E6.

Similar connections are then made as the bonding integrity checks (Fig. E5) and the 'Earth loop' resistance (R_3) of the two electrodes via the ground is measured.

If the two electrodes are separated by a large distance then the R_3 will approach the series resistance of R_1 + R_2. Lower measured values of R_3 indicate a degree of conductive coupling through the soil. Generally, for the purposes of checking satisfactory segregation of Earth Electrodes the following test is used: $R_3 > 0.9(R_1 + R_2)$. Values lower than $0.9(R_1 + R_2)$ may indicate inadequate separation and further investigation is required.