electricity north west
Bringing energy to your door

Code of Practice 335

Issue 4 July 2023

Earthing Design for 132kV, 33kV & 33/11/6.6kV Primary Substations and Equipment

Amendment Summary

ISSUE NO. DATE	DESCRIPTION
Issue 4 **July 2023**	Updated to new template Prepared by: Peter Twomey Approved by: Policy Approval Panel and signed on its behalf by Steve Cox, DSO Director

Contents

1 Introduction

Electricity Policy Document EPD333 describes the policy to be applied to the electricity distribution network owned by Electricity North West Limited, as Distribution Licensee.

This Code of Practice (CP) CP335 provides a means of complying with the policy in EPD333 for supply system earthing for 132kV, 33kV & 33/11/6.6kV primary substations and equipment. The earthing design for 6.6/11kV distribution substations and equipment is covered in CP333. In those cases where the simplified design approaches given in CP333 are not appropriate then the design principles given in this CP can be used to design a suitable earthing system.

The design is primarily based upon ENA TS 41-24 and ENA ER S34 but includes requirements from other standards such as BS EN 50522 where this is considered appropriate.

Where the reader is invited to seek specialist advice this shall be done via Policy & Implementation, Electricity North West Limited. Where the reader is an Independent Connection Provider advice shall be sought via Grid and Primary Connections, Electricity North West Limited.

2 Scope

This CP sets out the design criteria of the earthing systems for substations and equipment for 33kV and 132kV substations. The intention is to establish base parameters for determination of the earthing design to be implemented at a specific site. Compliance with this CP will ensure that a safe and efficient earthing system is implemented at each site.

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

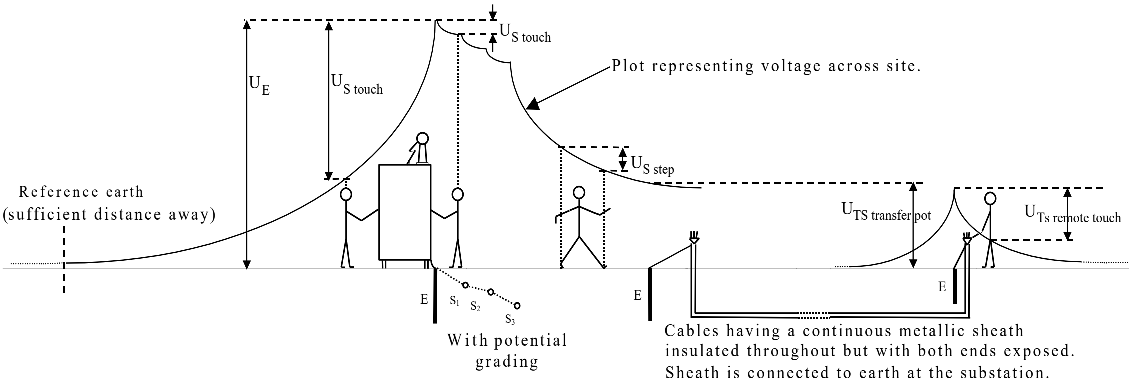
3 Definitions

For the purpose of this document the following definitions shall apply. (The definitions of the EPR, Remote Touch Voltage, Step Voltage, Touch Voltage and Transfer Potential are illustrated in the drawing in Figure 1)

BSP	Bulk Supply Point - 132/33kV or 132/11/6.6kV Substation
EPR	Earth Potential Rise. The potential on exposed metalwork and the earth electrode or conductor during fault conditions, relative to remote (or 'true') earth. Note that this value will differ at various points on a large earthing system and should be considered for all voltage levels within a substation.
'Cold' Substation	A substation where the Earth Potential Rise does not exceed the value specified in this specification (Table 2) when the maximum earth fault current is flowing.
GSP	Grid Supply Point – 400/275kV to Lower Voltage Substation

'Hot' Substation	A substation where the Earth Potential Rise can exceed the value specified in this specification (Table 2) when the maximum earth fault current is flowing.
Remote Touch	The potential difference between a connected conductor (e.g. a metallic sheath
Voltage	or pipe) and earth at a remote point when the object is earthed both in the substation and also at the remote end. (Compare with Transfer Potential below, which is defined as the voltage for touching if the object is earthed in the substation but not at the remote end).
Step Voltage	Potential differences are established on the surface of the soil whilst fault current is flowing. Step Voltage in a particular direction is defined as the potential difference between two points a metre apart. Step potentials can be reduced by using potential grading electrodes or installing electrodes at a greater depth.
Transfer Potential	A potential rise of an earthing system caused by a current flowing to earth, transferred by means of a connected conductor (e.g. a metallic sheath or pipe), which enters an area, with little or no potential rise relative to reference earth, and which is not connected to earth in that area. This results in a potential difference occurring between the conductor and its surroundings at the remote position.
Touch Voltage	The potential difference between any item of metalwork and the soil around it (creating a hand-to-feet voltage difference) during the time that fault current flows. Touch voltages are calculated assuming that the feet of the person are 1m away from the metalwork being touched. Touch voltages are normally reduced by using potential grading electrodes such as buried copper tape or meshes intended to equalise potentials around equipment.

Figure 1 – Touch, Step and Transfer Potentials at an Electricity Substation



Where:

E	Earth electrode
U_E	Earth potential rise (EPR)
S_1, S_2, S_3	Potential grading earth electrodes (e.g. ring earth electrodes), each connected to the earth electrode (rod) E
$U_{S\ touch}$	Source voltage for touching (Touch Voltage)
$U_{S\ step}$	Source voltage for step (Step Voltage)
$U_{TS\ transfer\ pot}$	Transferred source voltage for touching if the sheath is earthed in the substation and not at the remote end (Transfer Potential)
$U_{TS\ remote\ touch}$	Transferred source voltage for touching if the sheath is earthed at the remote end as well (Remote Touch Voltage)

4 Work Practices to Minimise Risk

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

4.1 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 cables. Reference to the appropriate utilities' records and the use of approved instruments for the detection of buried services may be necessary.

4.2 Bonding and Connections Between Metalwork

All normally accessible metalwork, such as transformer tanks, LV pillar enclosure, metal fencing, metal tapes in non-metallic casing, etc. will 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 C. Only copper conductors shall be buried, and special attention shall be given to forming good joints having anti-corrosive performance. 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.

4.3 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 shall 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 of CP333, and to CP411LV.

5 General Design

The design is based on the requirements laid down in ENA TS 41-24, which in turn derive (in part) from BS EN 50522.

The design shall ensure that a substation is 'safe' in that all touch, step and transfer voltages are within acceptable limits. This shall be achieved for the ENWL substation without reliance on any associated customer earthing installation, e.g. a co-located solar / wind generation site or a customer distribution network.

The design should aim to achieve a 'cold site', if practicable at reasonable cost. To meet this requirement the contribution from a co-located customer earthing system may be used.

The applicable touch and step voltage limits are described in ENA TS 41-24 and are a function of protection clearance time (higher limits exist for faster protection clearance and vice-versa). These are summarised in Section 5.3 below. In this regard, the design should consider worst case normal clearance times as described in 5.1 below, or actual clearance times if these are slower. The EPR (earth potential rise) and resultant touch/step voltages arising from faults at all voltage levels (including those outside the substation) must be considered using calculated (or worst case) earth-fault level or ground-return current (See 5.2).

Earthing Conductors in primary and grid substations shall be rated to carry the symmetrical three phase fault current corresponding to the Electricity North West Limited network rating for 3 seconds.

EPR, step and touch voltage calculations, shall be based on the values provided by Electricity North West Limited. These should be the actual calculated earth fault current and 3-phase fault currents as appropriate. Network fault currents can be found here: https://www.enwl.co.uk/get-connected/network-information/long-term-development-statement/policies-and-technical-references/system-earthing-and-fault-levels; a 10% factor should be applied to account for fault level growth throughout the lifetime of the installation.

The incoming and outgoing feeder arrangements shall be considered, and appropriate factors used to subtract the percentage of current that returns via overhead line earth wires or cable sheaths.

For all primary and grid designs, a computer model of the installation is required using an appropriate multi-layer soil model. The soil layer resistivities shall be determined by measurement at the proposed site (refer to Appendix E of CP335).

5.1 Fault Clearance Time

The fault clearance times detailed in Table 1 shall be applied on the Electricity North West Limited network, unless otherwise agreed. These are appropriate for EPR / safety calculations but not for conductor sizing, which must withstand slower (backup) protection operation and be rated to match the switchgear / system rating.

Table 1 – Fault Clearance Time

VOLTAGE	FAULT CLEARANCE TIME
132kV	0.2s
33kV	0.5s
6.6/11kV	1.0s

5.2 Earth Potential Rise (EPR) 'Hot' or 'Cold' Classification

Excessive levels of EPR may cause insulation breakdown, e.g. on LV cable sheaths with a remote earth reference. Where practicable the EPR should be limited to 3kV. Higher values may be acceptable, but the risks of insulation breakdown shall be considered and mitigated where necessary.

The Hot/Cold status of a site relates to its EPR as described below. When calculating the EPR (and step/touch voltages), it is important to consider the ground return current I_{GR} that could flow into the local electrode system. When the supply circuit(s) are all cable, a significant proportion of the earth fault current will return via the sheath(s), meaning that the EPR will be lower than if this metallic return path were absent[‡]. An earthed overhead line also provides a similar benefit.

The EPR at the new site is the product of ground return current (I_{GR}) and substation resistance R_A:

$$EPR = I_{GR} \times R_A$$

In practice, the apparent substation resistance (R_A) is reduced by cable or tower connections to the wider network. The designer should endeavour to achieve a **safe site** without reliance on this contribution[*]. The current return through cable sheath or OHL conductor may be considered (i.e. subtracted from I_E to give the nett earth return current I_{GR})

NOTE: For primary and grid substations it is assumed that cable sheath connections are reliable and duplicated via multiple parallel paths. If this is not the case and cable sheath connection failure is considered to be a foreseeable risk, the designer should proceed using I_E rather than I_{GR}, i.e. the design should be made safe for broken/absent cable sheaths where close to 100% of earth fault current might flow into the earth electrode system.

NOTE: The reason for not including the wider distribution network is because if this value is estimated then it could incorrectly affect the results. However, a measured value may be used if required and if achieving a safe site without this contribution is difficult to achieve, and if network connections are secure and reliable.

For **HOT / COLD** classification the wider distribution network may be included, even if this is based on a conservative estimate as described in CP333, and this reflects the normal operating arrangement for the network.

If alternate running arrangements are possible, and likely to be employed for any significant duration, the effect of these arrangements (on I_{GR}, touch and step, and Hot/Cold status) shall be considered.

The following limits set out in Table 2 shall be used to classify a substation as either 'hot' or 'cold' and will determine the course of action relating to telecommunication services provided to the substation.

NOTE: These limits are relevant to risk to third parties but are not directly relevant to safety of operational personnel or the public, which is determined by Touch, Step and Transfer Potential limits (see sections 5.3 & 5.4 below).

Table 2 – Design Maximum EPR for a 'Cold' Substation

VOLTAGE	EPR	COMMENTS
132kV	650V	Assumes all 132kV faults clear reliably within 0.2 seconds.
33kV	430V	All 33kV shall be considered to have low reliability communications, i.e. 0.2 second clearance cannot always be achieved.
6.6/11kV	430V	

The limits set out in Table 3 relate to telecommunication services and equipment outside of the substation (domestic telephones, modems, public telephones, main trunks, etc). They shall be used for liaison with BT/Openreach and other telecommunication operators as per the requirements of ENA ETR 129 and ENA EREC S36. In general, third party services should route outside these contours; if found to be within these contours, a risk assessment will be required as described in 5.5 below.

Table 3 – Thresholds for Liaison with Telecommunications Operators

EPR	COMMENTS
1150V	Slow clearance protection (average clearance time is 500ms) associated with 430V.
1700V	Fast clearance protection (average clearance time is 200ms) – associated with 650V threshold.

Care is required if ENWL substations are close to railways. The railway operator may wish to know the extent of the ENWL contours. Similarly, the impact of railway system faults and normal running EPRs should be considered. Under no circumstances should ENWL's earthing system be combined with that of the railway (even for LV connections) without an appropriate assessment of risks to both systems and to members of public.

Similar considerations exist where e.g. pipelines or national grid towers are within 50m radius of ENWL substations.

5.3 Touch and Step 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.

Normal shoes may be assumed in operational areas, for which appropriate ground coverings are normally soil, chippings, or (indoor) dry concrete.

Barefoot scenarios are applicable for some situations outside substations and these areas, if frequented, may be subject to risk assessment as Section 5.5.

The limits are set out in ENA TS 41-24 and summarised below for a range of clearance times and typical surface coverings (these are repeated in Appendix C for ease of reference).

Touch Voltage Limits

Permissible Touch Potentials[(A)] (V)	Protection clearance time											
	0.2	0.5	1	1.1	1.2	1.3	1.4	1.5	2	3	5	≥10[(B)]
Bare feet (with contact resistance) [(A)]	407	166	80	76	73	71	69	67	63	60	58	57
Shoes on soil or outdoor concrete	1570	578	233	219	209	200	193	188	173	162	156	153
Shoes on 75 mm chippings	1773	650	259	244	232	223	215	209	192	180	173	170
Shoes on 150 mm chippings or dry[(C)] concrete	2064	753	298	280	266	255	246	239	220	205	198	194
Shoes on 100 mm Asphalt [(D)]	10200	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 (>0.6 m) below ground level should be treated in the same way as soil.**
D. **The use of asphalt / tarmac will increase safety by providing an additional insulating layer under the operator's feet. However, it should be considered a last resort and should not be used as a substitute for a well-designed earthing system. If used, it must be maintained and kept free of cracking / weed / grass growth which will affect the integrity of the insulation.**

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.

At joint sites (e.g. solar farms), touch and step voltages in and around ENWL's substation should be safe without wider area network contribution / customer contribution (but allowing for sheath reduction). This gives confidence of ongoing safety should the network change etc., or if the customer site is decommissioned / removed.

It shall be standard practice to specify a layer of (between 75mm to 150mm deep - as appropriate) crushed rock or chippings over the substation site area not already covered by concrete or tarmac. As the above table shows, this improves the insulation under foot and allows a higher value of safe touch potential. A greater thickness of chippings has minimal effect on the tolerable voltage calculation but does improve the integrity of the insulation. Outside the site area, where crushed rock is not used, the lower values (soil) are applicable.

It is important to recognise that correct operation of protection devices and switches is assumed in determining the fault duration and the acceptable potential differences.

In substation areas, it shall not be possible for an individual to come between two different earthing systems hand-to-hand. This requirement is achieved by ensuring that different systems (e.g. fence and substation) are separated by 2m, or appropriate barriers used to prevent simultaneous contact. See section 6 / 7 below.

The permissible hand-to-hand voltage difference is dependent on protection clearance time, but as a rule of thumb a conservative limit of 55V applies.

5.4 Transfer Potentials

The substation earthing system design shall ensure that high transfer potentials do not exist. If transfer potentials can occur (e.g. along pilot cables), the potential grading at the remote end must be provided (see Figure 1 and the definition of Remote Touch Voltage). The potential grading shall provide similar protection to that at the primary substation. Operators should be aware of the dangers that may arise from breaking cable sheath connections or from working between systems (including earthed phases) that are earthed at two separate points – the use of temporary bonds or insulated working can help in this regard and is appropriate in cable joint bays as well as on the overhead system.

The voltage transferred to any LV system must not exceed 2× the appropriate touch voltage; generally, a limit of 430V is appropriate (this being close to 2×233V which is the 1 second touch voltage limit on soil). This is detailed further in CP333. In general, the LV neutral/earth MUST NOT be connected to any HOT site earth, and instead will be separately earthed outside the 430V contour.

Services coming into substations can bring in a remote (zero) reference and, if not bonded, could introduce a transfer potential hazard. Conversely, if they are bonded, they could carry a transfer potential hazard outside the substation. Extra care is needed in both cases if the substation is HOT. See Section 8 below.

5.5 Risk Assessment Approaches

Whilst the use of a 'Risk Assessment' approach to design, construction and maintenance is recognised within the Health and Safety legislation, it is not appropriate within substations. Instead, a deterministic approach based on limiting step/touch voltages as described in this document shall be used.

Risk assessment is a valid tool for assessing risk to third parties outside a substation, for example if a housing estate is to be built within the 'hot zone' of a pre-existing substation.

For new build, the designer should keep the 1150V (or 1700V for 132kV faults) contour away from properties where possible. If the situation is unavoidable and eliminating the Hot zone (making Cold) or reducing / re-shaping is not practical, the advice of a specialist or suitably qualified person should be sought.

In such cases a risk assessment may 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.

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

Computer modelling or detailed calculations are normally required to establish the extent of high EPR zones and their impact on third parties. The probability of fibrillation can be established based on the voltages across and individual person as described in IEC 60479-1. Reliable fault statistics and individual exposure rates are required to achieve a sensible figure for individual risk, and the designer should err on the side of caution (or appoint a suitable expert) if such information is not forthcoming or if calculated IR is unacceptable.

The ENA and BT have issued guidance on assessing the risk to telecommunications operators or other third parties from transferred potentials in the EPR zone of a substation. This risk assessment approach is contained in ENA ETR 128 and 129 and is based on the limits set out in ENA TS 41-24. As a general rule, isolation transformers / isolation units will be required for all telecoms circuits into HOT substations.

5.6 Impedance

The overall impedance to earth at a substation shall be calculated or measured to be the combined impedances, in parallel, of the earth grid, the chain impedance of any steel tower lines, together with the impedance to earth of any connected cable sheaths and any earth conductor laid adjacent to cable systems. Calculations must allow for overlapping areas of influence and for this reason computer modelling is more accurate.

ENWL requires that earthing system at new primary and grid sites **must be modelled** at the design stage – including step/touch potentials, using an appropriate multi-layer soil model.

5.7 Hot Sites

A site shall not be designed as 'hot' without the agreement of the Policy and Implementation Manager. In most cases a compromise will provide the best solution, i.e. some additional earthing work will be needed to reduce the EPR, but to a level where the site is still 'hot'. The design shall provide a safe environment for staff and the public within and adjacent to the substation.

In some circumstances, although the substation has to be declared 'hot', it will have been necessary to extend the earth grid outside the substation perimeter fence. When there is equipment* nearby which is prone to damage by rise of earth potential, it is sometimes possible to design the external electrode so that the hot zone avoids this equipment. Refer to the Policy and Implementation Manager for specialist advice.

It is possible to achieve safe step/touch potentials in a substation for any EPR, regardless of HOT/COLD status. In practice, an upper limit for EPR exists, this being the withstand voltage between earthing systems (e.g. typically between the substation and any LV network earth, if any). A figure of 2kV is used for 11kV:LV substations but can be exceeded at primary and grid substations provided adequate measures are taken to prevent danger in the event of a HV or EHV earth fault, and that these measures are documented and justified by design calculations and/or manufacturers' test data.

NOTE: such as petrol filling stations, chemical plants or telephone exchanges. This list is not exhaustive; equipment with a remote earth reference (comms cables, railway signals, etc.) or where stray voltages may serve as an ignition source require additional consideration.

5.8 Earthing Conductor Sizes

The substation earthing system shall have earth conductors sized in accordance with those in Table 5 below. The conductors forming the earth grid are loop connections and shall be sized accordingly. (The conductor sizes are selected from the range in ENA TS 41-24 tables 5 and 6). The designs shall 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. For protection and control panel earthing the conductor shall be 70mm^2. Spur connections shall be used to connect items of plant to the earth grid and these shall be duplicated to transformers and switchgear to provide increased capacity and resilience in the event of loss / theft / failure.

NOTE: Only copper shall be used for buried conductors.

Table 5 – Earthing Conductor Sizes

CONNECTION	SYSTEM VOLTAGE	
	6.6/11kV & 33kV	**132kV**
Spur Connections		
Copper Strip	32mm x 4mm	40mm x 6mm
Stranded Copper conductor	120mm^2	2 x 120mm^2
Aluminium Strip	50mm x 4mm	60mm x 6mm
Stranded Aluminium conductor	2 x 90mm^2	2 x 185mm^2
Duplicate or Loop Connections		
Copper Strip	25mm x 4mm	40mm x 4mm
Stranded Copper conductor	70 mm^2	150 mm^2
Aluminium Strip	25mm x 4mm	40mm x 6mm
Stranded Aluminium conductor	120 mm^2	185 mm^2

NOTE: Conductor sizes based on following fault currents - 6.6/11kV & 33kV at 13.1kA/3secs, and 22kA/3sec for 132kV. For higher fault levels (or alternative conductor sizes), consult ENA TS 41-24 tables 5 and 6.

5.9 Standard Earth Grid Design

A standard earth grid design arrangement shall preferably provide a 'cold' substation. The design will include the following features: -

Earthing conductors shall be buried at a minimum depth of 0.5m below ground surface. The extent of the perimeter of the earth grid shall be sufficient to contain within it all high voltage equipment and structures. This perimeter conductor shall be laid a minimum of 2m away from any metallic fencing and 1m away from exposed earthed metalwork, associated transformers, switches etc (i.e. separation between any item of plant and the metal fencing should ideally, be 3m). The perimeter conductor shall encapsulate an area as large as possible. Where the outer boundary is a wall, the perimeter conductor may be laid just inside this.

Equipment such as switchgear frames, transformer tanks, neutral earthing resistor tanks, structures supporting high voltage equipment etc shall be connected to the earth grid using at least two connections. It is generally preferred that these connections are of bare copper laid in the ground to contribute to the overall resistance to earth. They shall however use the shortest direct route between the earth grid and primary equipment.

Whenever additional electrodes are required within the confines of the perimeter conductor, these shall comprise lengths of bare copper conductor. Standard earth rods may be connected to such lengths along their routes. Test facilities, as shown in Appendix A, shall be provided to 10% of substation earth rods (minimum of two) to allow maintenance testing.

Longer rods may be necessary in some soils or to reduce the grid resistance. Where rods of more than 5m length are used connections as shown in Appendix A shall be used, see also COP430. The long rods and connections shall be at the edges of the site, and ideally as opposite pairs spaced greater than their depth. The use of a clamp meter will permit rapid periodic testing (see measurement section of CP333).

The switchroom reinforcing bars / mesh under and around the switchgear shall be connected to the main earthing system using multiple connections to ensure reliability. This will (fortuitously) improve the earth grid resistance value by a small amount, and (most significantly) lower the touch voltage in the switchroom area. The improvement to the earth grid resistance value shall not be included in the earth grid resistance calculations without prior agreement with Electricity North West Limited.

The adequacy of the earthing design arrangement is a function of several variable quantities. The outline design shall be referred to a person of adequate competency who will validate the final design. The design shall be confirmed as correct using calculations as necessary.

Where calculations demonstrate that a proposed arrangement is not satisfactory to limit touch and EPR to within the limits specified in 5.2 and/or 5.3 respectively, additional measures to bring these values to within acceptable limits shall be considered and verified by further calculation.

The preferred additional measures to be used to reduce the substation earthing resistance and thereby reduce touch voltage and EPR rise to within acceptable limits are:

- Additional earth grid mesh conductors
- Additional or longer earth rods. This is particularly relevant where access to lower resistivity soil can be achieved at lower depths

- Supplementary earth conductors in cable trenches or in separate trenches emanating from the substation. However, if the substation remains 'hot', this action may extend the hot zone outside the substation.

- Extend the length of buried earth conductor outside the substation perimeter and bond it to the main earth system.

Computer modelling (e.g. SAFEGrid or CDEGS) should be used to explore the most efficient solutions.

Any connection in the earth grid system shall be arranged so that the earthing is still maintained with one connection lost; this is of particular importance at sites with connection to generators or NGET. Measures should be taken to reduce theft, such as concrete covering/capping of below ground electrode, pinning / covering above ground conductor, and use of less attractive materials above ground. Certain points in the system (such as transformer star points) are critical and every effort shall be taken to preserve the integrity of earth connections to these components. See 5.12 below.

5.10 Jointing and Connection of Earth Systems

Connection of equipment to the earth grid shall be by means of compression fittings or bolted clamps complying with BS 951. Other methods of connection can be used where specifically approved.

The surface of all earthing and bonding connections buried in the ground shall be of copper. Copper to aluminium conductor joints shall be made at least 250mm above ground level by means of an approved type of bi-metal joint.

Earth grid connections shall be by exothermic weld or brazed connections.

5.11 Soil Resistivity

Where detailed calculations are required soil resistivity tests shall be carried out. Further guidance is given in Appendix B.

5.12 Anti-Theft Measures

Guidance is provided in CP998.

To prevent theft of the earth electrode by pulling it out of the ground it may be anchored via vertical rods or sections of the electrode may be encased in low sulphur concrete or similar proprietary materials as approved by ENWL.

Earthing conductor theft can be discouraged by suitable fixing to structures and use of camouflage, anti-vandal or bitumastic paint where required. For security fixing to concrete or steel structures, stainless steel anchors (i.e. Alcomet FNA II or approved equivalent) shall be used, generally spaced at 300mm centres.

6 Metallic Fence Earthing

6.1 Standard Earth Grid Designs

Third parties are not permitted to connect their fences directly to the substation metal fence. A connection of this type could introduce a transfer potential risk. Third party metalwork must not be simultaneously accessible, i.e. ideally should be greater than 2m from substation fences and/or barriered or insulated using approved methods. The use of insulated fence sections or stand-off insulators (to create a floating panel) may be considered.

The fencing is situated external to the substation grid and is designated an independently earthed fence. A metal fence therefore requires its own earthing arrangements which must be kept electrically segregated from the earth grid, i.e. positioned at least 2m away from grid electrodes. In addition to the above ground separation, this segregation is based on a 2m clearance in the ground between any electrodes associated with the fence and those associated with the earth grid to provide electrical separation between the two systems.

Earth electrodes for metallic fencing shall consist of standard earth rods driven to a minimum of 2.4m depth. Fence earth rods should be close to the fence and not infringe the 2m clearance zone. These shall be installed as follows: -

(a) Adjacent to each corner.

(b) One metre either side of the crossing point of each overhead power circuit.

(c) For larger sites, at intervals not exceeding 50m.

(d) At gate posts and at removable sections of fence.

Gate posts, and posts at each side of removable sections of fence, shall be bonded together to prevent potential differences arising, since both parts can be bridged by a person opening the gate or removing the fence panel. The bond connection shall be made by laying a buried conductor from one post to the other. The bond connection to each post shall be visible, i.e. above ground level. Flexible bonds of 35mm^2 copper braid shall be used to connect each gate to its appropriate post.

When a fence is separately earthed, then any earth tape or external service entry or metal pipe or hessian served cable passing under the fence shall be insulated, or run in insulated ducts, for a distance of 2m either side of the fence.

Earthed metal poles for security lighting, etc. must not be erected within this 2m spacing. Insulated support columns are permitted. (Existing structures should be removed / barriered or subject to risk assessment to determine the extent of measures necessary to reduce risk to acceptable levels).

Where extraneous metalwork such as barbed wire or other metallic anti-climbing devices are erected along the top of walls etc., these shall be connected to the fence earthing electrode system. Care must be taken to ensure such sections do not bridge insulated fence sections.

6.2 Earth System Extending Beyond Fencing (Bonded Fence)

Where the grid outer electrode is to be laid outside the fencing, the fencing shall be connected to the grid at the following locations:

(a) Adjacent to each corner.

(b) One metre either side of the crossing point of each overhead power circuit.

(c) For larger sites, at intervals not exceeding 50m.

(d) At gate posts.

NOTE: Where the grid outer electrode is significantly more than 1m outside the fence another electrode, approximately 1m outside the fence, may be required to reduce touch voltages on the fence. Computer modelling should be used to evaluate whether this is required. It may also be necessary to establish and maintain a >1m section of chipping or tarmac outside the fence line to further control touch voltages.

Gate posts, and posts at each side of removable sections of fence, shall be bonded together to prevent potential differences arising, since both parts can be bridged by a person opening the gate or removing the fence panel. The bond connection shall be made by laying a buried conductor from one post to the other. The bond connection to each post shall be visible, i.e. above ground level. Flexible bonds of $35mm^2$ copper braid shall be used to connect each gate to its appropriate post.

Where extraneous metalwork such as barbed wire or other metallic anti-climbing devices are erected along the top of walls etc., these shall be connected to the fence earthing electrode system, taking care not to bridge any insulated sections where these exist.

6.3 Plastic Covered Chain Link Fencing

Although the insulated nature of such fencing could be said, in its new condition to be compatible with unearthed fencing, in the long term metal may become exposed. Such fencing shall be earthed by bonding the support posts, straining wires, barbed wire and anti-climbing devices to the independent or integrated earth electrode as appropriate. In addition, the fencing shall be regularly inspected and repaired as necessary.

6.4 Insulated Fence Sections

In some situations, it will be necessary to introduce insulated fence sections, for example to separate lengths of fencing which are to be bonded to the main earth grid from those which are to be independently earthed. Wholly insulated fence sections are available for this purpose but are not strong enough to be used for the outer perimeter fence. However, they can be used for internal fences.

Insulated sections for external use are the traditional palisade type, sometimes coated with high quality PVC insulation. This section is normally 2m long, will not be earthed and will have insulated joint connections at each end. The insulated joints will comprise 50mm stand-off insulators, ideally capable of withstanding 3kV rms for 3 seconds. Insulated joints having higher withstand capability may be required if the substations EPR can exceed 3kV.

If a fence is electrified then it cannot easily be used as an insulated section as the electrification wires include earth conductors, however the need can be addressed if necessary on an individual basis using underground bridge wires or similar across these sections.

6.5 Earthing of Metallic Fencing at Complex Sites E.g. Multi-Use Locations

For complex sites and those involving third party equipment refer to the Head of Safety and Policy for specialist advice. Hybrid fence arrangement (part bonded, part separately earthed) may be appropriate. In some situations, an additional (perhaps wooden or otherwise insulated) outer fence can provide a solution.

7 Substation Requirements

7.1 33kV to 11kV/6.6kV Primary Substations

7.1.1 General

For primary substations in urban areas the design shall be such that the site is classified as "cold".

For substations in non-urban areas it shall be standard practice to render the site 'cold', wherever this is practicable at reasonable cost. If it appears that extensive, costly modifications would be required to make the site 'cold', an assessment shall be made of the costs involved in declaring the site 'hot'.

The earthing design of a primary substation shall be in accordance with the standard drawing (No 900215-102).

7.1.2 Non Standard Sites

If the earthing design of the substation complies with the standard drawing and the site is still "hot" a suitable combination of the following additional measures may be carried out to reduce the earth grid resistance and render the site cold:

- Lay copper conductor with incoming or outgoing HV or EHV power cables
- Install longer earth rods
- Install additional copper tape mesh

If the design cannot comply with the distances in the standard drawing and the site is classified as "cold" the following additional measures shall be carried out:

- The fence shall be bonded to the perimeter electrode.
- The perimeter electrode shall be installed as close to fence as possible
- Calculations shall be provided to prove the site is within limits of tables 2 and 4.

If the site is hot and no additional measures can render it cold, then computer modelling shall be used to establish whether the site can be made safe. This can be difficult if the site footprint is small and >2m clearances to a separately earthed fence cannot be maintained; however, these issues can usually be addressed. If third party properties exist close to the site, and safety cannot be assured, or if other concerns arise an alternative site shall be sought.

7.2 GSP and BSP Substations

7.2.1 General

It shall be standard practice to render the site 'cold', wherever this is practicable at reasonable cost. If it appears that extensive, costly modifications would be required to make the site 'cold', an assessment must be made of the costs involved in declaring the site 'hot'.

The earthing design of a BSP substation shall be in accordance with the standard drawing (No 900215-101). Due to variations in GSP substations a standard drawing is not provided. However, standard practice for GSP earthing designs shall be to comply with the general principles shown on the BSP standard drawing.

7.2.2 Reduction of EPR, Touch Voltage or Step Voltage

To reduce the EPR, touch voltage or step voltage the earth system could be extended beyond the perimeter fence

The designs normally will be similar to the standard design but will usually include the following features: -

- The perimeter of the earth grid will extend for 1m or more outside any metallic fencing.
- Where the grid is being extended either to make the substation 'cold', or to limit the EPR, the outer conductor may be spaced more than 1m away from the fence-line at a distance indicated in the design study. Depending on wayleaves and practical issues, the outer electrode spacing from the fence may not be symmetrical. For example, it may be 1m away on one side and 15m away on the other. Another conductor, approximately 1m outside the fence, is likely to be needed in the latter case, to reduce touch voltages on the fence. This arrangement of earthing will provide a bonded fence arrangement. Ownership and security of the system must be considered before deeming it an acceptable solution.
- Metal fencing will be connected to the earth grid in those areas where the perimeter conductor is beyond it, as described in section 6.

7.3 High Frequency Earths for Capacitor Voltage Transformers (CVTs) and Surge Arresters)

Capacitor voltage transformers and surge arrestors shall have a low impedance path to earth to prevent voltage transients appearing at the earthed end of the equipment.

Unless a low impedance earth connection to the MES is provided, the effectiveness of a surge arrestor could be impaired and high transient potentials appear on the earthing connections local to the equipment. The following installation earthing arrangements are recommended, as described in ENATS 41-24:

Two connections to earth are required for both surge arrestors and CVTs:

- The first connection (for power frequency earthing) will use the structure to connect to the MES.
- The second (high frequency) connection should be direct to an earth rod, installed vertically in the ground as near to the surge arrestor base as possible, with a tee connection to the support structure if metal. High frequency earth rods should be driven vertically into the ground to a depth of approximately 4.8m. Where this is not achievable, a high-density earth mesh arrangement of four (or more) long horizontally buried conductors (nominally 10m in length, minimum depth 600mm) dispersed at 90° (or less, equally spaced across the full 360°) may be used in place of the rod. Calculations should be provided to demonstrate that any proposal is equivalent to the 4.8m long earth rods. The high frequency connection should be made to the centre of the alternative high frequency designs. Dedicated earth mats or similar may be considered for difficult circumstances.

NOTE: see BS EN 62305-1, BS EN 62561-2 and ENA ETR 134 for more information.

CVT earthing shall be in accordance with the standard drawing 900198-422 and surge arrester earthing shall be in accordance with the standard drawings 900198-022, 900198-030 or 900198-502 as applicable.

8 Hot Sites

8.1 General

The earthing designs shall be verified using computer modelling to ensure that touch and step potentials are acceptable for faults at all voltage levels in the substation.

8.2 Actions to be Taken at Substations Designated as "Hot"

Where it becomes necessary to designate the substation as 'hot', the following actions shall be carried out:

- The hot zone contour distance shall be determined by the use of an approved substation earthing calculation program

- The 'hot' substation designation and the extent of the hot zone shall be recorded in the hot site database.

- An isolation transformer shall be specified where the telecommunication service(s) enters the appropriate building.

- All metallic services to the site and building shall be given attention to ensure they do not introduce a transfer potential risk. This can be prevented by introduction of insulated inserts (normally one inside the substation and another 2m beyond the perimeter fence). Alternatively, the water supply could be provided by a plastic pipe from 2m outside the perimeter of the substation. Any exposed metal or services must be bonded to the substation earth grid if there is any possibility of simultaneous contact. (See below for discussion of LV services to the site).

- Any operational problems associated with work on pilot cables, telecommunication and power circuits shall be identified and addressed through appropriate procedures for induced voltage working.

NOTE: Work on pilots at 132kV and 33kV substation sites would normally be treated as if the site was 'hot' and so only unusual situations need to be separately identified for pilots

- LV services shall not be provided to Hot substations from the nearby network unless derived from a dedicated transformer with separate HV/LV earthing, and then only if the rated withstand voltage between both systems (in entirety) is sufficient to cope with the worst case EPR. LV earths should be bonded to the main substation earth to prevent touch potential in the substation. The use of a network derived LV service will export high EPR onto the LV system which could be hazardous and is not acceptable without special measures to ensure safety.

  Alternative arrangements exist for supplying hot substations. Possible methods include the use of isolation transformers or overhead sections / insulated glands to keep different earthing systems apart. Refer to CP278 – auxiliary supplies. Note that such supplies will either be deliberately separated or combined; care should be taken not to inadvertently alter existing arrangements.

This requirement is also applicable for supplies to NGET sites. Further guidance on the requirements for NGET sites can be obtained from National Grid Technical Specification (NGTS) 3.1.2.

Refer to the Head of Safety and Policy for specialist advice.

8.3 Actions to be taken Where Hot Zone Extends Outside Substation Perimeter

Where the final arrangements mean that a substation will have a hot zone that extends outside the substation perimeter fence, the following steps shall be initiated:

- BT/Openreach or other telecommunication companies, who use metallic cables, shall be advised when the limits in Table 3 are exceeded. They will require telecommunication cable in the substation to be terminated via an isolation unit and may require additional insulation or protective measures on any equipment passing within the hot zone area.

- Other Bodies (Gas, Water, the Petro-chemical industry, etc.), having buried metallic pipework within the hot zone shall be advised so that precautions can be taken by their staff whilst working on any metalwork within the zone. Again, there may be financial costs involved for additional protective measures. Some pipeline operators require a 50m clearance from all substations.

- When there is equipment (e.g. petrol filling stations, chemical plants or BT exchanges) nearby which is prone to damage by rise of earth potential, it is sometimes possible to design the external electrode so that the hot zone avoids this equipment

  Risk assessment methods may be appropriate for assessing risk per person per year , outside the substation, as outlined in BS EN 50522 Annex NA and repeated in this document (section 5.5). Appropriate statistics for 'EPR Events Per Year' should be requested from suitably qualified personnel.

NOTE:

The requirements in this section apply only to what is termed 'conductive' interference. 'Inductive' interference (i.e. situations where a fault current flowing in power cables or lines may cause inductive interference in nearby cables or metallic structures) is not considered in this CP. Refer to the Policy and Implementation Manager for specialist advice on inductive interference.

Impressed voltages from cable sheaths, tower lines, etc. can be calculated using formulae or approved software. Various special cases exist (such as supplies to radio masts on Transmission Towers etc.; refer to ENA ER G78 and to ENWL CP 278.

9 Requirements for Final Design

The final design shall: -

- Include the earth grid resistance and overall earth return impedance values.

- Include the EPR, for a maximum value of earth fault current. This shall be calculated for all voltage levels at the substation. It should be calculated with and without network contribution. HOT/COLD status, safety voltages, and EPR may ultimately be assessed with network contribution, if known with a reasonable degree of certainty (i.e. if network has been modelled or measured) and there are duplicate (multiple cable sheath) robust connections to the network without any single points of failure.

- Specify whether the substation is 'hot' or 'cold'.
- Show the limits of the hot zone - if applicable.
- Confirm that the internal maximum touch and step potentials at all points are below the safe acceptable value for all foreseeable running arrangements.
- Confirm that, the maximum touch potentials at the fence are below the safe, acceptable value.
- Confirm that the maximum external step potentials are below the safe acceptable value.
- Where the design makes significant use of vertical rods include the calculation of the fault current distribution within the grid. This should ensure that copper earth rods can carry their proportion of current without damage. The electrode surface current density should be evaluated, and additional electrode added if required to reduce to acceptable levels (refer to Appendix B8 of CP333).
- Where a NGET site is in close proximity to an Electricity North West Limited site and there is a possibility of return current passing to NGET via the Electricity North West Limited earthing system, include calculations, which demonstrate that the Electricity North West Limited system can carry the current without damage.
- If it has been agreed that the reinforcing bar is included in the earth grid resistance, include calculations of the current density in the reinforcing bars, so that the temperature rise can be predicted. This must be sufficiently low that the concrete is not damaged. Generally, steel-reinforcing bars should have formal copper electrodes outside them to divert the majority of fault current away.

10 Design Records

For all new substations a record of the earthing design calculations, recording detail of the earth grid design and demonstrating compliance with the stated limits of touch voltage and ground potential rise, together with a record of hot zone radius, where applicable, shall be retained. Drawings will be stored on Meridian and calculations shall be retained with the scheme paperwork.

11 Requirements for Independent Connection Providers

In addition to the requirements detailed within this document Independent Connection Providers shall also comply with the following:

- Detailed calculations, and computer modelling to confirm resistance and touch voltages for every installation shall be submitted before civil work starts. All assumptions / data sources shall be listed.
- Reasonable notice shall be given to Electricity North West Limited to permit approval of the installation at appropriate stages during construction.

12 Documents Referenced

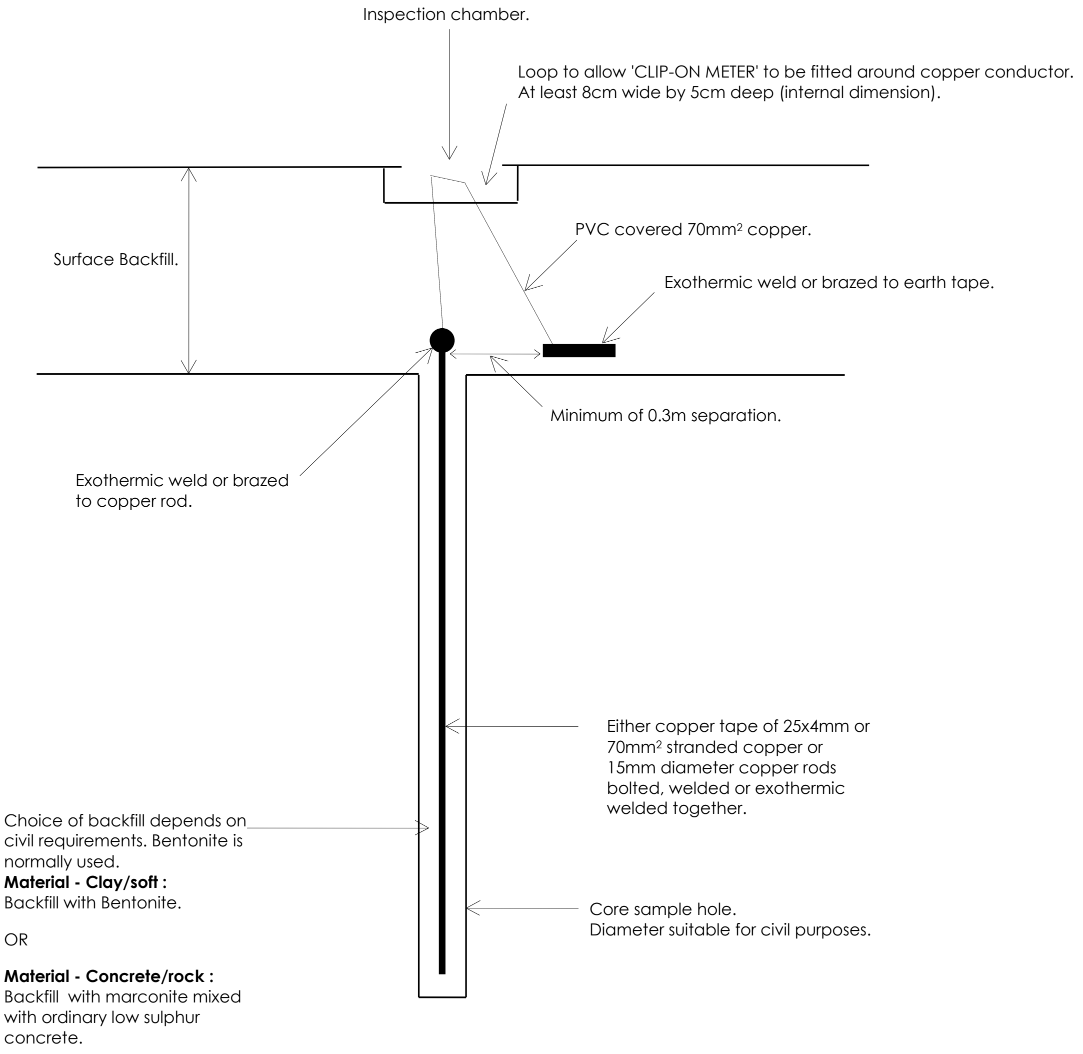
DOCUMENTS REFERENCED	
BS 951	Specification for Clamps for Earthing and Bonding Purposes
ENA ETR 128	Risk Assessment for BT Operators Working in a ROEP Zone
ENA ETR 129	ROEP Risk Assessment for Third Parties using Equipment Connected to BT Lines
ENA ER S34 (2018)	A Guide for Assessing the Rise of Earth Potential at Substation Sites
ENA TS 41-24 (2018)	Guidelines for the Design, Installation, Testing & Maintenance of Main Earthing Systems in Substations
NGTS 3.1.2	Substation Earthing
EPD333	Supply System Earthing
CP333	Earthing Design for 11/6.6kV Distribution Substations and Equipment

13 Keywords

Earth; HV; MV; Substation

Appendix A – Connection of Earth Rod to Main Earth via Copper Flexible to Facilitate Testing

(Install for Long Rods (>5m) And 10% Of Rods in a Substation with a Minimum of Two)



This allows individual rod resistance values to be tested with a clip-on meter and facilitates electrode tracing, when necessary during maintenance or construction. Rods may be manually driven or inserted in pre-bored holes, such as geo-technical core sample drillings.

Appendix B

B1 Ground 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 shall be used for initial assessment only. Table B1 provides typical ground resistivity values (Reference ENA TS 41-24, Table 3).

Table B1 – 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 3000
Rock	1000 to 10000

The ground resistivity at a site may be measured using the Wenner method (refer to CP 333 Appendix E), using traditional earth resistance testers with four electrodes. An alternative method is to drive an earth rod in a position required for the actual earthing system and to measure its resistance. This resistance should ideally be derived as the result of the average of four rod measurements. The rod resistance shall be measured using the fall of potential method and the equivalent ground resistivity calculated from one of the following formulae:

$\rho = 1.4$ R for a 1.2m test rod

$\rho = 2.48$ R for a 2.4m test rod

Where ρ is the equivalent ground resistivity (Ωm) and R is the measured rod resistance (Ω).

This technique will generally provide an adequately accurate assessment of ground resistivity for the earthing system calculations.

Accurate determination of the ground resistivity at the proposed site using the Wenner method requires the use of electrode spacing (and thus soil depth) up to 50m if practicable. Where ground resistivity varies with depth equivalent ground resistivity should be derived using multi-layer model techniques and specialist advice is required.

Appendix C – Data Tables

Table C1 – Approved 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.
NOTE: 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.

For equipotential bonding of non-current carrying equipment, 70mm^2 stranded copper conductor (or equivalent) shall be used as standard. In some situations, if there is absolute certainty that earth fault current will not divert through the bonds (e.g. if equipment is small/standalone without alternative connections to earth) then a smaller size (min 16mm^2 copper or equivalent) may be used for design economy.

Touch and Step 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 C2 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 the below section.

Table C2

Permissible Touch Potentials[A] (V)	Protection clearance time											
	0.2	0.5	1	1.1	1.2	1.3	1.4	1.5	2	3	5	≥10[B]
Bare feet (with contact resistance) [A]	407	166	80	76	73	71	69	67	63	60	58	57
Shoes on soil or outdoor concrete	1570	578	233	219	209	200	193	188	173	162	156	153
Shoes on 75 mm chippings	1773	650	259	244	232	223	215	209	192	180	173	170
Shoes on 150 mm chippings or dry[C] concrete	2064	753	298	280	266	255	246	239	220	205	198	194
Shoes on 100 mm Asphalt	10200	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 (>0.6 m) below ground level should be treated in the same way as soil.

C2 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.