WESTERN POWER DISTRIBUTION

Serving the Midlands, South West and Wales

Company Directive

STANDARD TECHNIQUE: TP21DD

Design of Earthing Systems
Part D
Ground Mounted Distribution Substations

Summary

This Standard Technique defines the earthing design requirements for ground mounted distribution substations which are to be owned or adopted by Western Power Distribution.

Author: **Graham Brewster**

Implementation Date: **June 2021**

Approved By:

Engineering Policy Manager

Date: **28th June 2021**

Target Staff Group	**Network Services Teams, Engineering Trainers & ICPs**
Impact of Change	**AMBER - The changes have an impact of current working practices that are not safety critical – Communication at next team meeting or as part of a retraining programme**
Planned Assurance checks	**Policy Compliance Specialists shall confirm whether the requirements have been complied with during their sample checking of completed jobs**

IMPLEMENTATION PLAN

Introduction

This Standard Technique defines the earthing design requirements for ground mounted distribution substations which are to be owned or adopted by Western Power Distribution.

Main Changes

ENA TS 41-24 & S34 have been revised. These are Distribution Code Annex 2 documents and it is a breach of the Code (& hence Licence Conditions) not to comply.

This ST implements the latest requirements. Whilst it is a new document, it supersedes parts of Standard Technique TP21D/3.

Impact of Changes

Target Staff Group	Network Services Teams, Engineering Trainers & ICPs involved with the design and construction of earthing systems for ground mounted distribution substations
Impact of Change	AMBER - The changes have an impact of current working practices that are not safety critical – Communication at next team meeting or as part of a retraining programme

Implementation Actions

- Managers to notify relevant staff & Contractors that this document has been published
- This document to be made available to ICPs on the www.westernpowertechinfo.co.uk website
- TP21D to be marked up to indicate the sections that have been superseded
- There are no retrospective actions

Implementation Timetable

This ST shall be implemented with effect from 1st August 2021.

Where a connection offer is accepted prior to this date, the substation may be constructed in accordance with the requirements applicable at the time of acceptance, subject to the construction works being completed on or before 31st December 2021.

Where a requote is provided after the release of this document, the connection offer shall comply with the requirements of this document.

REVISION HISTORY

Document Revision & Review Table		
Date	**Comments**	**Author**
June 2021	• Initial issue	Graham Brewster

Contents

1.0 INTRODUCTION

This Standard Technique defines the earthing design requirements for 6.6kV and 11kV ground mounted distribution substations which are to be owned or adopted by Western Power Distribution.

Earth potential rise can present an electric shock hazard. A potential difference across parts of the human body causes current to flow, and there is a risk of fatal electric shock if the current flows for sufficient time to cause ventricular fibrillation of the heart. Previously, a threshold of 430V [1] was employed, i.e. the earthing system was deemed to be safe if the HV earth potential rise was 430V or less. IEC 60479-1 defines a series of time-current curves for judging whether ventricular fibrillation of the heart will occur. These curves mean that the previous unconditional 430V limit is no longer tenable.

2.0 DEFINITIONS

For the purpose of this document the following definitions are employed:

TERM	DEFINITION
Earth Electrode	A conductor or group of conductors in direct contact with the soil and providing an electrical connection to earth.
Earthing Conductor	A protective conductor which connects plant and equipment to an earth electrode.
Earthing System	The complete interconnected assembly of earthing conductors and earth electrodes (including cables with un-insulated sheaths).
Reference Earth	Part of the Earth, the electric potential of which is conventionally taken as zero.
Earth Potential Rise (EPR)	The difference in potential which may exist between a point on the ground and remote reference earth.
Electrode Resistance	The impedance between the earthing system and remote reference earth.
Step Voltage	The potential difference between a person's feet which are 1m apart
Touch Voltage	The potential difference between a person's hands and feet when standing 1m away from the object they are touching
Stress Voltage	The potential difference between locally and remotely earthed parts of cables, plant and apparatus that appears across cable/sheath insulation or across insulators/bushings during an earth fault condition and which, if sufficiently large enough, could result in insulation breakdown, flashover or failure.

[1] Or 650V if the earth fault causing the potential rise is cleared by fast acting, high reliability protection which limits the fault duration to 200ms or less.

TERM	DEFINITION
Transfer Voltage	The potential transferred by a long metallic object which is connected to earth at one or more points and which bridges locations that are at different potentials with respect to the general mass of earth. As such, the object may transmit the potential rise of an earthing system into an area with low or no potential rise, or transmit reference earth into an area of potential rise, resulting in a potential difference occurring between the object and its surroundings.
Cold Site [2]	A site where the earth potential rise (EPR) or the transfer potential from the source substation is: • Less than 430V (or 650V where high reliability protection with a fault clearance time less than 200ms is employed), and • Less than the touch voltage limit for shoes on soil or outdoor concrete *[Except at HV/LV substations where the neutral of the LV system is connected to earth at multiple locations (i.e. a PME LV system) where the applicable value is less than 2x the touch voltage limit for shoes on soil or outdoor concrete]*
Hot Site [2]	A site which is not a cold site i.e. a site where the earth potential rise (EPR) or the transfer potential from the source substation is: • Greater than 430V (or 650V where high reliability protection with a fault clearance time less than 200ms is employed), and • Greater than the touch voltage limit for shoes on soil or outdoor concrete *[Except at HV/LV substations where the neutral of the LV system is connected to earth at multiple locations (i.e. a PME LV system) where the applicable value is greater than 2x the touch voltage limit for shoes on soil or outdoor concrete]*
Ventricular Fibrillation	A state of the heart in which the lower chambers (ventricles) twitch randomly (fibrillate) instead of contacting in a co-ordinated fashion, resulting in an inability to pump blood. Considered to be the main mechanism of death in fatal electrical accidents

[2] This is a WPD definition which differs from that in ENA TS 41-24 (which relates to the 430V / 650V limit for telecommunication equipment). It is a reflection of the fact that the terms ‘hot’ & ‘cold’ have become ubiquitous within WPD to mean sites where HV & LV earths should be segregated / combined, and where limits for telecommunication equipment have / have not been exceeded respectively.

3.0 REFERENCES

This document makes reference to, or should be read in conjunction with, the documents listed below. The issue and date of the documents listed below shall be those applicable at the date of issue of this document, unless stated otherwise.

3.1 IEC Standards

NUMBER	TITLE
IEC 60479-1	Effects of current on human beings and livestock - Part 1: General aspects

3.2 British Standards

NUMBER	TITLE
BS EN 50522	Earthing of power installations exceeding 1 kV a.c.
BS EN 62305	Protection against lightning

3.3 Energy Networks Association

NUMBER	TITLE
ENA TS 41-24	Guidelines for the design, installation, testing and maintenance of main earthing systems in substations

4.0 DESIGN REQUIREMENTS

Earthing systems for ground mounted distribution substations shall:

- Satisfy statutory requirements.
- Present a low impedance to earth fault current in order that protection systems can operate assuredly.
- Prevent hazardous voltages appearing in and around the substation.
- Minimise equipment damage from stress voltages caused by earth potential rise.
- Ensure that voltages transferred onto the LV system neutral/earth conductors as a consequence of HV faults do not present a hazard.
- Ensure that voltages transferred onto telecommunication systems as a consequence of HV faults do not present a hazard.
- Comply with the requirements for substation LV earthing where PME systems are employed.

4.1 **Design Margin**

The following margin [3] shall be incorporated into the earthing system design for ground mounted distribution substations:

a) The 'design' earth potential rise shall be 10% in excess of the 'calculated' earth potential rise.
b) The 'design' fault clearance time shall be 400ms in excess of the 'calculated' fault clearance time.

4.2 **Requirements For HV Earth Electrodes**

The following design criteria shall be satisfied for HV earth electrodes associated with ground mounted distribution substations:

a) The HV earth electrode and associated earthing conductor shall have a cross sectional area of at least $70mm^2$, a minimum strand diameter of 2.5mm where stranded copper conductor is employed, and a minimum thickness of 3mm where copper earth tape is employed.
b) The HV earth electrode shall have a resistance as low as is reasonably practicable but not greater than 20Ω for 11kV substations and 15Ω for 6.6kV substations. The 20Ω / 15Ω limit shall be realised solely by the installed HV electrode i.e. it shall not include any parallel earth contribution from network[4].

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[3] Also known as the 'safety margin'. The additional capability required to compensate for uncertainties or network evolution over the lifetime of the substation. In other words, when assessing compliance with safety and equipment limits, the touch, step, transfer and stress voltages are projected to be greater in magnitude and persist for longer than calculations suggest.

[4] The parallel earth contribution from the network can be utilised to reduce the resistance of the HV earth electrode below the 20Ω / 15Ω limit, but not to achieve it.

c) The HV earth electrode shall, where practicable, include a ring electrode surrounding the substation, with a 1200mm long, 12.7mm diameter earth rod at each corner.

d) The HV earth electrode shall also consist of a horizontal electrode 'tail' laid in a radial direction away from the substation.

e) The surface area of the HV earth electrode in contact with the ground shall be large enough to prevent the soil around the electrode drying and increasing in resistance during a fault.

f) All equipment / conductive parts within the substation, including rebar, shall be bonded to the HV earth electrode.

g) The earth potential rise shall be 3kV or less in order to ensure equipment stress voltages are not exceeded.

h) Touch and step voltages shall be within safety limits both inside and immediately outside the distribution substation.

i) There shall be an above ground separation of at least 2.5m between any metallic part which is bonded to the HV earth electrode and any extraneous conductive part[5].

j) Where the magnitude of the earth potential rise exceeds the touch voltage limit for shoes on soil or outdoor concrete for the HV fault clearance time of the distribution substation, the HV electrode shall be separated by sufficient below-ground distance (the HV separation distance) from the following installations such that the potential impressed on them as a result of a HV fault is maintained within the touch voltage limit:

   - Railway or tramway [6]
   - Telephone exchange
   - Pipeline with cathodic protection
   - Zoo, stable or pond/lake used for commercial fishing
   - Outdoor swimming pool, outdoor paddling pool, or outdoor shower
   - Customer TT electrode
   - Bulk storage tank for petrol or flammable liquid
   - SNE/TN-S LV systems, along with buildings and enclosures equipped with an electrical installation supplied from this system [7]

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[5] A conductive part liable to introduce a potential, generally earth potential, for example, metal fences, crash barriers, street lighting columns etc.

[6] The touch voltage limit for railways and tramways is specified in TP21A-B

[7] An LV system which is connected to earth at a single location only. Note that true SNE/TN-S systems are quite rare as many have been converted over time to 'SNE via CNE' systems i.e. are earthed at multiple locations, in which case the requirements for PME/CNE/TN-C systems apply.

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k) Where the magnitude of the earth potential rise exceeds 2x the touch voltage limit for shoes on soil or outdoor concrete for the fault clearance time of the distribution substation, the HV electrode shall be separated by sufficient below-ground distance (the HV separation distance) from the following installations such that the potential impressed on them as a result of a HV fault is maintained within 2x the touch voltage limit:

    – WPD PME/CNE/TN-C LV system, along with buildings and enclosures equipped with an electrical installation supplied from this system [8]

4.3 Additional Requirements For WPD HV/LV Substations

Where a ground-mounted distribution substation contains a WPD owned HV/LV transformer the HV & LV earth electrodes should be combined where at all possible. Where the criteria for combined HV & LV earth electrodes cannot be met, then segregated HV and LV earth electrodes shall be provided.

4.3.1 Requirements For Combined HV & LV Earth Electrodes

The earthing system shall comply with the following design criteria in order for combined HV & LV earth electrodes to be employed:

a) Where the LV neutral is to be connected to earth at multiple locations (i.e. a CNE/PME/TN-C LV system or an SNE/TN-S LV system that has been modified to permit for PME connections), the magnitude of the earth potential rise shall be less than 2x the touch voltage limit for shoes on soil or outdoor concrete for the HV fault clearance time.

b) Where the LV neutral is to be connected to earth only at the distribution substation (i.e. a true SNE/TN-S LV system), the earth potential rise shall be less than 1x the touch voltage limit for the HV fault clearance time for shoes on soil or outdoor concrete.

c) The earth potential rise shall be 430V or less in order to ensure limits for telecommunication equipment are not exceeded.

d) Where the distribution substation is cable connected to the source substation, the voltage transferred from the source substation to the distribution substation in the event of an EHV (i.e. 33kV, 66kV or 132kV) fault shall be:

    – Less than 2x the touch voltage limit for shoes on soil or outdoor concrete for the 33kV, 66kV or 132kV fault clearance time where the LV neutral is to be connected to earth at multiple locations (i.e. a CNE/PME/TN-C LV system or an SNE/TN-S LV system that has been modified to permit for PME connections).

[8] An LV system which is connected to earth at multiple locations. It includes SNE/TN-S systems that are actually ‘SNE via CNE’ systems.

- Less than 1x the touch voltage limit for shoes on soil or outdoor concrete for the 33kV, 66kV or 132kV fault clearance time where the LV neutral is to be connected to earth at only at the distribution substation (i.e. a true SNE/TN-S LV system).
- Less than 430V, or less than 650V where the 33kV, 66kV or 132kV faults are cleared by high reliability protection with a fault clearance time less than 200ms.

4.3.2 Requirements For Segregated HV & LV Earth Electrodes

The earthing system shall comply with the following design criteria where segregated HV & LV earth electrodes are required:

a) The LV earth electrode shall consist of a horizontal electrode laid in a radial direction away from the substation.

b) The LV earth electrode shall have a cross sectional area of at least 70mm^2, a minimum strand diameter of 2.5mm where stranded copper conductor is employed, and a minimum thickness of 3mm where copper earth tape is employed.

c) The LV earth electrode shall have a maximum resistance of 20Ω for 11kV substations and 15Ω for 6.6kV substations. The resistance shall be determined solely by the installed electrode i.e. shall not include any parallel earth contribution from network.

d) The electrode shall be insulated and laid within a 38mm diameter, Class 3, general purpose duct for buried electric cables where it is within the HV separation distance of the HV earth electrode (see Section 4.2 above).

e) The length of the uninsulated/'bare' portion of the electrode shall never be less than 10m.

4.4 Additional Requirements For HV Connection Substations Connecting WPD Customers

This section should be read in conjunction with ST: SD4OA (11kV and 6.6kV Connections to Customers and IDNOs using Secondary Switchgear).

In this arrangement the WPD HV switchgear is close-coupled to:

- A WPD metering unit, and WPD's HV Customer is connected via a cable box on the metering unit

4.4.1 Design Responsibility For Earthing Arrangements At WPD Customer Connections

The HV earth electrode associated with WPD's HV switchgear shall be owned and maintained by WPD.

WPD shall have design responsibility for the earthing arrangements on equipment located entirely within the area covered by the WPD HV earthing system (i.e. within the perimeter electrode).

The WPD Customer's HV & LV systems are connected beyond the WPD "supply terminals" [9] and outside of the perimeter electrode, and consequently are outside of the jurisdiction of WPD. Accordingly, it is the Customer's responsibility to ensure the earthing arrangements on its HV & LV systems are adequate.

4.4.2 WPD's Obligations

The Management of Health & Safety At Work Regulations requires employers to co-operate and co-ordinate where they share a workplace. The regulations require WPD to take all reasonable steps to inform the other employers concerned of the risks to their employees' health and safety arising out of or in connection with the operation of the distribution network.

The Construction (Design & Management) Regulations requires designers and contractors to co-operate when working on or in relation to a project, at the same or an adjoining construction site.

The Electricity Safety, Quality & Continuity Regulations requires WPD to withhold its consent to the making or altering of the connection from the distribution network to a WPD Customer's installation where there are reasonable grounds for believing that the WPD Customer's installation, or the connection itself, is not so constructed, installed, protected and used so as to prevent danger or interruption of supply.

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[9] Supply terminals means the end of the WPD owned electric lines at which the supply is delivered to the Customer's installation. Also known as the point of supply.

From an earthing design perspective this will typically mean:

- Informing the WPD Customer of the earth potential rise and fault clearance time of the WPD substation in order that the Customer can eliminate or mitigate foreseeable risks to health or safety, so far as is reasonably practicable
- Withholding consent to make or alter a connection to the WPD distribution network where there are reasonable grounds for believing that the Customer's earthing system is not designed and installed so as to prevent danger.

4.4.3 Additional Requirements For The WPD HV Earth Electrode

WPD shall, where at all possible, provide an HV earthing system for its substation which is adequate to ensure safety in the absence of the earthing system provided by the WPD Customer.

Where two distribution substations supply the WPD Customer and these are located in close proximity to each other[10], the two HV earth electrodes shall be interconnected with an earth bond having a minimum cross sectional area of $70mm^2$.

4.4.4 Requirements For The WPD Customer's HV Earth Electrodes

The earthing system for the WPD Customer's HV substation shall satisfy the following requirements:

a) The earthing system shall be designed in accordance with BS EN 50522 or BS 7430. Alternatively, the Customer may elect to design the earthing system in accordance with ENA TS 41-24 or the relevant WPD directives.

b) The Customer shall, where at all possible, provide an HV earthing system for its installation which is adequate to ensure safety in the absence of the earthing system provided by WPD.

c) The Customer's HV electrode shall, in the absence of any interconnection to the WPD earthing system, have a maximum earth resistance as specified in the table below. This ensures there will be sufficient earth fault current to operate the protection even if the interconnections between the WPD and Customer earthing systems have been compromised.

Voltage	Maximum Earth Resistance
11,000V	20Ω
6,600V	15Ω

[10] For example, two non-extensible Ring Main Units positioned less than 10m apart

4.4.5 Requirements For Interconnecting The WPD And WPD Customer's HV Earth Electrodes

The WPD and WPD Customer HV earthing systems shall be interconnected with two earth bonds, each with a minimum cross sectional area of $70mm^2$.

The earth bonds shall be laid on diverse routes and connected to different parts of the Customer's HV electrode in order to mitigate against accidental disconnection or severing of both connections concurrently.

The bonds shall be insulated and laid in ducts for their entire length.

The ends of the earth bonds in the WPD distribution substation shall be clearly identifiable in order that periodic testing can be undertaken to assess whether interconnection has been lost.

Guidance Note

These earth bonds are in addition to any interconnection provided by the sheath of any HV cable between the WPD and Customer substations.

These earth bonds are particularly important where the WPD or Customer substations are dependent upon each other in order to ensure safety.

Bonding the WPD and Customer HV earthing systems together allows standard steel wire armoured multi-core and multi-pair cables to be employed across the WPD - HV Customer interface.

4.4.6 Requirements For The WPD Customer's HV/LV Substation

The WPD Customer's HV/LV substation is connected beyond the WPD "supply terminals" [11] and outside of the perimeter electrode, and consequently is outside of the jurisdiction of WPD.

The Customer is responsible for ensuring the HV & LV earth electrodes associated with its HV/LV transformer(s) are designed, installed and used in such a manner to prevent danger occurring in the Customer's LV network as a result of any fault in the Customer's HV system or on the WPD HV network. In other words, deciding whether to combine or segregate the associated HV and LV earthing systems.

Guidance Note

BS EN 50522 states that "w*here the LV system is totally confined within the area covered by the HV earthing system both earthing systems shall be interconnected*". Where the electrical installation at the Customer's premises satisfies this condition, the HV and LV earth electrodes will often be combined, even if the earth potential rise is greater than the touch voltage limit for shoes on soil or outdoor concrete for the fault clearance time, or greater than 430V. This clause is also a reflection that, for industrial and commercial installations, it is not practicable to separate earthing systems due to the close proximity of equipment.

[11] Supply terminals means the end of the WPD owned electric lines at which the supply is delivered to the Customer's installation. Also known as the point of supply.

Note that where WPD owns the HV/LV transformer the LV system invariably leaves the area covered by the HV earthing system and hence does not satisfy this BS EN 50522 condition. Consequently WPD company policy is for its HV and LV earthing systems to be segregated where the earth potential rise is greater than the touch voltage limit for shoes on soil or outdoor concrete for the fault clearance time, or greater than 430V.

Electricity Safety, Quality & Continuity Regulation 8(2)(b) states that a generator shall, in respect of any high voltage network which he owns or operates, ensure that the earth electrodes are designed, installed and used in such a manner so as to prevent danger occurring in any low voltage network as a result of any fault in the high voltage network. Regulation 8(5) states that Regulation 8(2)(b) shall not apply to a network which is situated within a generating station if, and only if, adequate alternative arrangements are in place to prevent danger. Accordingly, HV Customers who are 'generators' may also elect to combine HV and LV earth electrodes, even if the earth potential rise is high.

4.5 Additional Requirements For HV Connection Substations Connecting IDNOs

This section should be read in conjunction with ST: SD4OA (11kV and 6.6kV Connections to Customers and IDNOs using Secondary Switchgear).

There are essentially three arrangements employed at ground mounted distribution substations connecting IDNOs, namely:

- WPD HV switchgear close-coupled to an IDNO cable
- WPD HV switchgear close-coupled to an IDNO transformer
- WPD HV switchgear close-coupled to an IDNO metering unit

In all cases, the HV earth electrode associated with WPD's HV switchgear shall be owned and maintained by WPD.

4.5.1 Design Responsibility For Earthing Arrangements On IDNO Connections

4.5.1.1 WPD Switchgear Close-Coupled To An IDNO Cable

In this arrangement the WPD HV switchgear is close-coupled to a cable box, inside which the IDNO's HV cable is terminated. In other words, the ground mounted distribution substation provides HV supplies to an IDNO network.

WPD has design responsibility for the earthing arrangements at the distribution substation because, apart from the cable termination, the IDNO has no other HV assets at the substation.

4.5.1.2 WPD Switchgear Close-Coupled To An IDNO Transformer

In this arrangement the WPD HV switchgear is close-coupled to an IDNO HV/LV transformer and LV fuse cabinet. The IDNO transformer provides LV supplies to the IDNO network.

The close-coupling means that the IDNO’s HV assets are located entirely within the area covered by the WPD HV earthing system. Accordingly, WPD has design responsibility for the HV earthing arrangements at the distribution substation.

The IDNO’s LV network invariably leaves the area covered by the WPD HV earthing system. Accordingly, it is the IDNO’s responsibility to ensure the earthing arrangements on its LV network are adequate. This includes designing and installing LV earthing systems in such a manner so as to prevent danger occurring in the IDNO’s LV network as a result of any fault in the IDNO’s or WPD’s HV assets.

4.5.1.3 WPD Switchgear Close-Coupled To An IDNO Metering Unit

In this arrangement the WPD HV switchgear is close-coupled to an IDNO metering unit. The IDNO’s HV customer is connected via the cable box on the metering unit.

The close-coupling means that the IDNO’s HV assets are located entirely within the area covered by the WPD HV earthing system. Accordingly, WPD has design responsibility for the HV earthing arrangements at the distribution substation.

The IDNO Customer has HV & LV systems which leave the area covered by the WPD HV earthing system. The IDNO Customer is responsible for ensuring the HV & LV earth electrodes associated with its HV/LV transformer(s) are designed, installed and used in such a manner to prevent danger occurring in its LV installation as a result of any fault in the Customer’s HV system, or on the IDNO HV equipment, or on the WPD HV equipment. In other words, deciding whether to combine or segregate the associated HV and LV earthing systems.

Since the IDNO Customer is to be connected to the IDNO network, it is the responsibility of the IDNO to carry out the ESQC Regulation 25 obligations (Connections to installations or to other networks).

4.5.2 WPD’s Obligations

The Management of Health & Safety At Work Regulations requires employers to co-operate and co-ordinate where they share a workplace. The regulations require WPD to take all reasonable steps to inform the other employers concerned of the risks to their employees’ health and safety arising out of or in connection with the operation of the distribution network.

The Construction (Design & Management) Regulations requires designers and contractors to co-operate when working on or in relation to a project, at the same or an adjoining construction site.

The Electricity Safety, Quality & Continuity Regulations (ESQCR) requires WPD to disclose such information to the IDNO as might reasonably be required and to otherwise co-operate with the IDNO in order to ensure compliance with the Regulations.

The ESQCR requires WPD to withhold its consent to the making or altering of the connection from the distribution network to an IDNO's network where there are reasonable grounds for believing that the IDNO's network or the connection itself is not so constructed, installed, protected and used so as to prevent danger or interruption of supply.

From an earthing design perspective this will typically means informing the IDNO of the earth potential rise and fault clearance time of the WPD substation in order that the IDNO can eliminate or mitigate foreseeable risks to health or safety, so far as is reasonably practicable.

4.5.3 Additional Requirements For The WPD HV Earth Electrode

Where two distribution substations supply the IDNO and are located in close proximity to each other the two HV earth electrodes shall be interconnected with an earth bond having a minimum cross sectional area of $70mm^2$.

4.5.4 Requirements For The IDNO HV/LV Substation

The IDNO HV/LV substation is connected beyond the WPD "supply terminals" and consequently is outside of the jurisdiction of WPD.

The IDNO is responsible for ensuring the HV & LV earth electrodes associated with the HV/LV transformer(s) are designed, installed and used in such a manner to prevent danger occurring in the IDNO's LV network as a result of any fault in the IDNO HV equipment, or on the WPD HV equipment. In other words, deciding whether to combine or segregate the associated HV and LV earthing systems.

4.5.5 Requirements For The IDNO Customer HV Earth Electrode

The IDNO Customer is connected to the IDNO network and consequently is outside of the jurisdiction of WPD.

The IDNO is responsible for specifying the requirements for the IDNO Customer's HV Electrode. It is strongly recommended that requirement c) in Section 4.4.4 above is applied as a minimum in order to ensure the WPD protection system is able to detect and operate for HV earth faults in the IDNO Customer's installation.

4.6 **Standard Designs**

Standard designs of ground mounted distribution substations shall be identified from the following list.

SUBSTATION FORMAT	ASSOCIATED STANDARD TECHNIQUE
Unit Substation In Freestanding GRP or Masonry Housing	TP21G-A
Unit Substation Integrated Within A Larger Building	TP21G-B
Padmount Substation	TP21G-C

SUBSTATION FORMAT	ASSOCIATED STANDARD TECHNIQUE
LV Connection Substation In Freestanding GRP or Masonry Housing	TP21G-E
LV Connection Substation Integrated Within A Larger Building	TP21G-F
HV Connection Substation In Freestanding GRP or Masonry Housing	TP21G-G
HV Connection Substation Integrated Within A Larger Building	TP21G-H

The associated Standard Technique(s) shall be read in conjunction with this document. They include:

- An Excel calculation tool for the earthing design calculations and other assessments required by this Standard Technique
- Detailed construction information for the earthing system

4.7 Special Designs

Special designs of ground mounted distribution substations shall be identified from the following list.

SUBSTATION FORMAT	ASSOCIATED STANDARD TECHNIQUE
HV & LV supplies to power stations or substations which have an operating voltage in excess of 20kV	TP21F-A
HV & LV supplies to mobile phone base stations or other equipment mounted on steel overhead line towers or poles	TP21F-B
HV & LV Non-traction supplies to AC electrified railways	TP21F-D
HV Traction Supplies To DC Light Rapid Transit Systems	TP21F-E
LV Non-Traction Supplies To DC Light Rapid Transit Systems	TP21F-E

The associated Standard Technique(s) shall be read in conjunction with this document. They include detailed construction information for the earthing system.

4.8 Bespoke Designs

Standard Techniques communicate WPD requirements in relation to standard and special designs. Occasionally it is necessary to construct a ground mounted distribution substation in a format not covered by the Standard Techniques.

In these instances the spirit of the closest matching of the aforementioned associated Standard Techniques shall be followed. Engineering judgement, within the limits of an individual’s competence, shall be exercised where appropriate, and advice should be sought from the WPD ‘Engineering Policy’ team where necessary.

Where the ground mounted distribution substation is located within 20m of the following installations it is recommended that an Earthing Specialist is engaged to carry out a bespoke design:

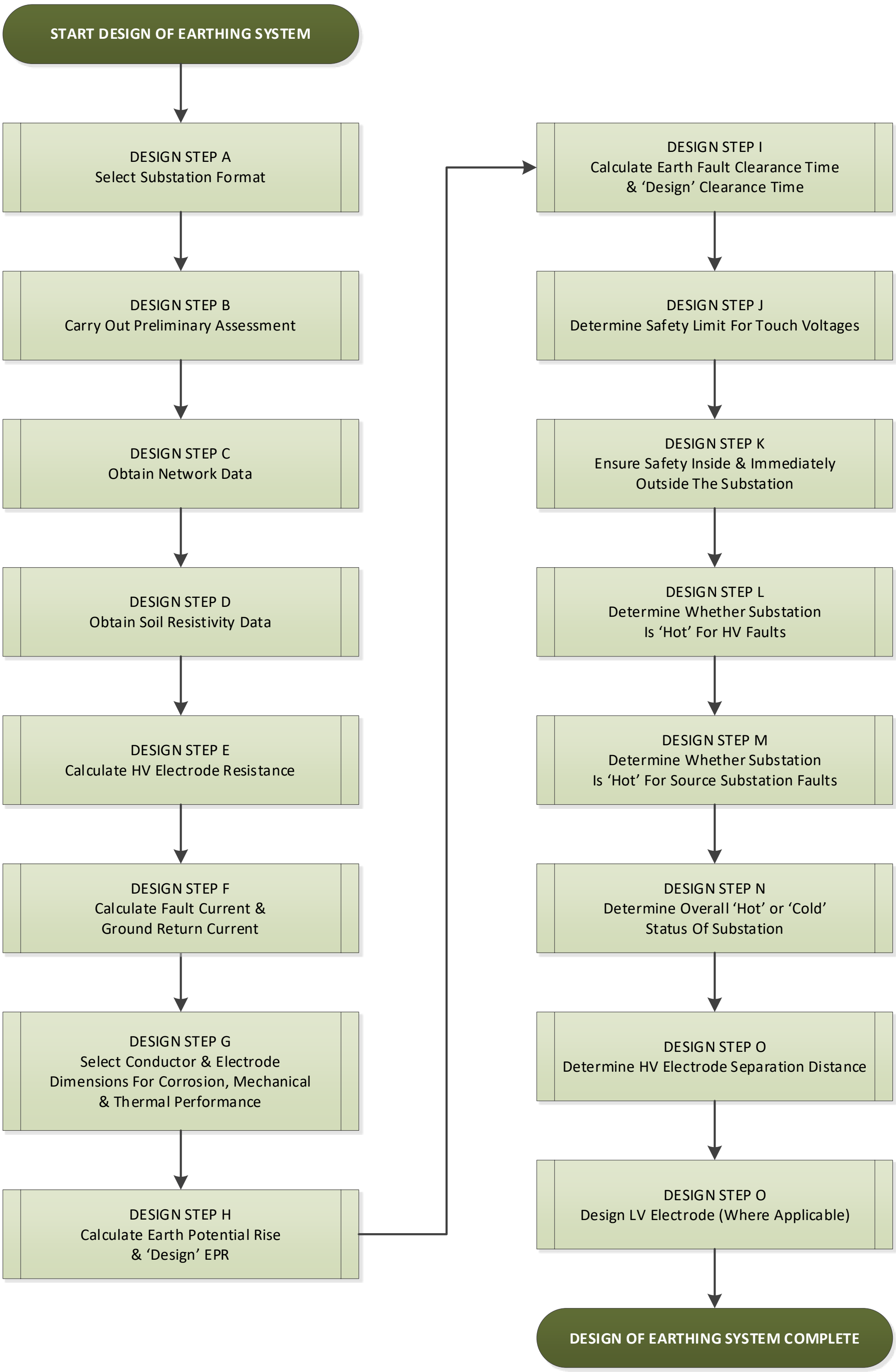
- Railway or tramway
- Telephone exchange
- Pipeline[12]
- Bulk storage tank for petrol or flammable liquid
- Zoo, stable or pond/lake used for commercial fishing
- Outdoor swimming pool, outdoor paddling pool, or outdoor shower
- Steel tower/pole operating at 132kV, 275kV or 400kV

HV separation distances in excess of 40m are considered to be unrealistic to achieve and maintain in practice. In these instances it is recommended that an Earthing Specialist is engaged to carry out a bespoke design.

[12] Means a system of large bore metal pipes (together with associated apparatus and works) used to convey oil, gas, or other fluids. It does not include small bore metal pipes used to convey fluids to domestic premises, or pipes used for domestic purposes.

5.0 DESIGN PROCEDURE

The overall earthing design procedure is shown in the flowchart below. The aspects which make up each design step are described in subsequent sections of this document.



5.1 DESIGN STEP A: Select Substation Format

The primary consideration when selecting the substation format is whether the substation requires a special earthing system design i.e. it comes under the auspices of one of the special designs listed in Section 4.7 above.

The substation format should be selected from the list of 'standard' or 'special' designs, as appropriate.

The design of the earthing system should be carried out in accordance with this document and the associated Standard Technique for the 'standard' or 'special' design.

5.2 DESIGN STEP B: Preliminary Assessment

A preliminary assessment shall be carried out to identify whether the proposed location of the ground mounted distribution substation is likely to prove challenging to the earthing system design.

Problematic locations include within 20m of the following:

a) An outdoor swimming pool, outdoor paddling pool, or outdoor shower

b) A zoo, stable or pond/lake used for commercial fishing

c) A telephone exchange

d) A railway or tramway

e) A metallic pipeline

f) A bulk storage tank for petrol or flammable liquid

g) A steel tower or steel pole overhead line operating at 132kV, 275kV or 400kV

Installation of ground mounted distribution substations in problematic locations shall be avoided where at all possible. Where this is unavoidable, an Earthing Specialist shall be employed to model the earthing system and carry out detailed analysis using appropriate and commercially available earthing design software tools[13].

[13] One example is "CDEGS" (Current Distribution Electromagnetic Interference Grounding and Soil Structure Analysis) by Safe Engineering Services & Technologies Ltd. Earthing design software tools by other vendors are available.

5.3 DESIGN STEP C: Obtain Network Data

Network data up to the HV terminals of the ground mounted distribution substation shall be obtained in order to enable earthing design calculations to be performed. The following information is required in order to expedite these calculations:

5.3.1 Source Grid / Primary Substation Details

The following details shall be obtained for the source Grid or Primary substation:

a) Earthing system impedance

b) Earth potential rise

c) Clearance time for a 33kV / 66kV / 132kV fault

5.3.2 HV System Neutral Earthing Arrangements At The Source Grid / Primary Substation

The system neutral-earthing arrangements at the source Grid / Primary substation shall be obtained, specifically, the number of neutral-earth connections, the type of earthing employed[14], and the current rating of each connection.

5.3.3 HV Circuit Impedance Data

The impedance of the HV circuit between the source substation and the ground mounted distribution substation shall be obtained by measuring the route length of each cable and overhead line section which makes up this connection and multiplying it by the impedance per kilometre for the relevant conductor type.

5.3.4 HV Cable Details

The following details shall be obtained for the HV cable leading back towards the source substation:

a) Whether it is cable all the way back to the source substation or only to a pole termination

b) The total cable length back to the source substation or pole termination, as appropriate

c) The predominant cable type in the connection to the source substation or pole termination, as appropriate

d) The earthing system impedance of the pole termination

Note that item d) is only required where the cable connection leads to a pole termination. Where this information is unknown, or cannot easily be measured, a 20Ω value should be assumed.

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[14] Resistance-earthing, reactance-earthing or direct-earthing

5.3.5 Local HV & LV Network Details

The built-up area covered by the local HV & LV network and the predominant cable type for this network shall be obtained.

The urban area shall be shall be determined in accordance with Standard Technique TP21A-I.

5.4 DESIGN STEP D: Obtain Soil Resistivity Data

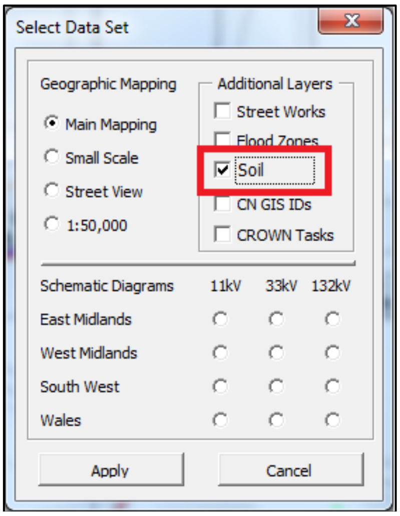
Soil resistivity data shall be obtained for the proposed ground mounted distribution substation.

The soil resistivity data should ideally be obtained by measurement on site using the procedure outlined in Standard Technique TP21O-A.

Alternatively, soil resistivity data shall be obtained from EMU using the following procedure:

a) Ensure the 'Soil' layer is enabled in the data set

- Click on 'Emu'
- Click on 'Select Data Set'
- Check the 'Soil' checkbox, as shown below

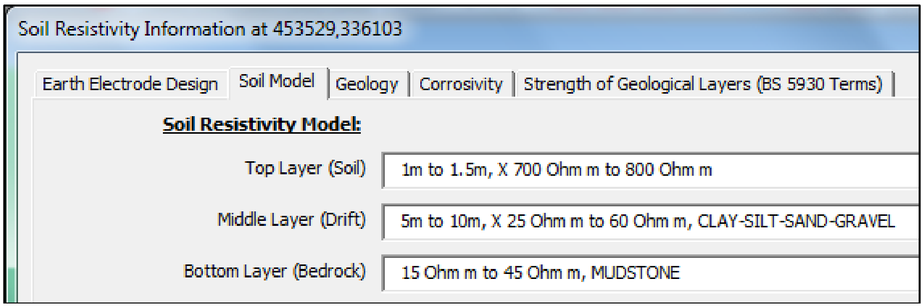


b) Find the location of the ground mounted substation on the geographical map.

c) Click on the 'Information' icon 

d) Place the cursor on the location of the substation and click

e) Select the 'Soil Model' tab. The soil resistivity data is shown as a three layer model, as shown below



5.5 DESIGN STEP E: Calculate Substation HV Electrode Resistance

5.5.1 Calculate Substation HV Electrode Resistance (R_E)

The HV electrode resistance (R_E) shall be calculated using the geometry of the electrode and the soil resistivity information. The calculations can be performed using earthing design software tools such as CDEGS[15] or by using the formulae in Appendix B of ENA EREC S34 Issue 2. The preferred approach is to calculate the electrode resistance using an earthing design software tool and a two layer soil resistivity model.

An HV electrode arrangement shall be selected such that its resistance (excluding network contribution) is as low as is reasonably practicable but not greater than 20Ω for 11kV substations and 15Ω for 6.6kV substations.

5.5.2 Estimate Network Contribution To Earth Resistance (R_{NC})

An estimate of the network contribution to the earth resistance (R_{NC}) shall be determined in accordance with Standard Technique TP21A-I.

The network contribution shall be the assessed value or the electrode resistance of the source substation, whichever is the greater.

5.5.3 Calculate Overall Earth Impedance (R_{GMSUB})

The overall earth resistance is the parallel combination of the HV electrode resistance and the network contribution to earth resistance.

$$R_{GMSUB} = \frac{1}{\frac{1}{R_E} + \frac{1}{R_{NC}}} = \frac{R_E \times R_{NC}}{R_E + R_{NC}}$$

[15] "CDEGS" (Current Distribution Electromagnetic Interference Grounding and Soil Structure Analysis) by Safe Engineering Services & Technologies Ltd. Earthing design software tools by other vendors are available.

5.6 DESIGN STEP F: Calculate Fault Current & Ground Return Current

5.6.1 Calculate Total Earth Fault Current (I_F)

The total earth fault current at the ground mounted substation (I_F) shall be calculated taking account of the:

- Earth electrode resistance of the source substation
- HV system neutral-earthing impedance at the source substation
- The impedance of the line and cable sections between the source substation and the ground mounted distribution substation
- HV earth electrode resistance of the ground mounted distribution substation
- The system impedance up to the source substation

Impedance data can be expressed in various ways, for example, in ohms or percentage or per-unit format. The latter two are specified as a multiple of a selected base power, normally 10MVA or 100MVA. Consequently it is necessary to convert them to a common format prior to carrying out the computations.

The total earth fault current (I_F) shall be determined in accordance with Standard Technique TP21A-F.

Note that a simplified calculation, which neglects the system impedance up to the source substation, is acceptable as this results a in a more conservative assessment of earth fault current.

5.6.2 Calculate Fault Current Flowing Into Ground (I_{GR})

The fault current flowing into the ground (I_{GR}) is calculated by multiplying the total earth fault current (I_F) by the percentage of fault current that will flow into the ground ($\%I_{GR}$).

$$I_{GR} = \%I_{GR} \times I_F$$

The percentage of fault current that will flow into the ground ($\%I_{GR}$) shall be determined in accordance with Standard Technique TP21A-H.

5.7 DESIGN STEP G: Determine Conductor & Electrode Dimensions For Corrosion, Mechanical & Thermal Performance

5.7.1 Conductor Cross Sectional Area

In accordance with Section 4.2 above, the earth conductor shall have the following minimum conductor dimensions in order to have adequate corrosion, mechanical and current carrying performance:

- Minimum cross sectional area of $70mm^2$
- Minimum permissible thickness of copper strip / tape = 3mm
- Minimum strand diameter of stranded copper conductor = 2.5mm

Guidance Note

The minimum cross sectional area is significantly in excess of the cross section required to carry the anticipated levels of fault current for three seconds.

The surplus cross sectional area provides a margin for possible conductor corrosion over the life of the substation.

The minimum strip thickness of 3mm and strand diameter of 2.5mm ensures sufficient mechanical performance.

5.7.2 Electrode Surface Area

The soil surrounding an earth electrode has a much higher resistivity than the electrode conductor itself and consequently the fault current flowing through it will generate a greater temperature rise. The effect of the high temperature is to cause the soil to dry out, thus further increasing its resistivity, or even to produce steam, which may drive a separation between the soil and the electrode conductor.

For this reason the current rating of the electrode is very much lower than that implied by the current rating of the conductor and is related to its surface current density i.e. amperes per unit surface area.

The surface area of the earth electrode in contact with the ground shall be sufficiently large enough to prevent the ground around the electrode drying and increasing in resistance during a fault.

5.7.2.1 Calculate Minimum HV Electrode Surface Area Requirements

The minimum surface area of the HV earth electrode shall be determined in accordance with Standard Technique TP21A-J.

5.7.2.2 Assess Compliance With Minimum HV Electrode Surface Area Requirements

An assessment shall be carried out to determine if the surface area of the proposed HV earth electrode is equal to, or greater than, the minimum surface area calculated in Section 5.7.2.1 above. The assessment shall be carried out in accordance with Standard Technique TP21A-J.

Where the surface area of the HV electrode is insufficient, it is necessary to either increase the length of the HV electrode 'tail' or to construct the 'tail' from a number of parallel conductors spaced 100mm apart in the same trench.

In the case of the latter, the close spacing of these parallel conductors means there will be no reduction in electrode resistance, but it is a way of significantly increasing the surface area of the electrode without having to increase the amount of excavation.

In the event that the HV earth electrode has to be extended in order to meet the minimum surface area requirement it will be necessary to redo Sections 0 onwards.

5.8 DESIGN STEP H: Calculate Earth Potential Rise (EPR) and 'Design' EPR

The earth potential rise (EPR) is calculated by multiplying the fault current that will flow into the ground (I_{GR}) by the overall earth impedance of the ground mounted distribution substation (R_{GMSUB}).

$$EPR = I_{GR} \times R_{GMSUB}$$

The 'design' earth potential rise shall be 10% in excess of the 'calculated' earth potential rise in accordance with Section 4.1 above.

5.9 DESIGN STEP I: Calculate Fault Clearance Time and 'Design' Fault Clearance Time

The earth fault clearance time should be calculated in accordance with Standard Technique TP21A-E using the total earth fault current (I_F), or a default value of three seconds should be employed.

Where the earth fault clearance time is calculated, it shall be based upon the tripping time[16] of the circuit breaker at the source substation and not on the tripping time of a circuit breaker downstream of this position, for example, a pole-mounted recloser.

The tripping time of the circuit breaker shall be based upon the fault being cleared by inverse-definite-minimum-time (IDMT) protection and not by instantaneous or definite-time protection.

The 'design' earth fault clearance time shall be 400ms in excess of the 'calculated' or 'default' fault clearance time in accordance with Section 4.1 above.

5.10 DESIGN STEP J: Determine Safety Limit For Touch Voltages

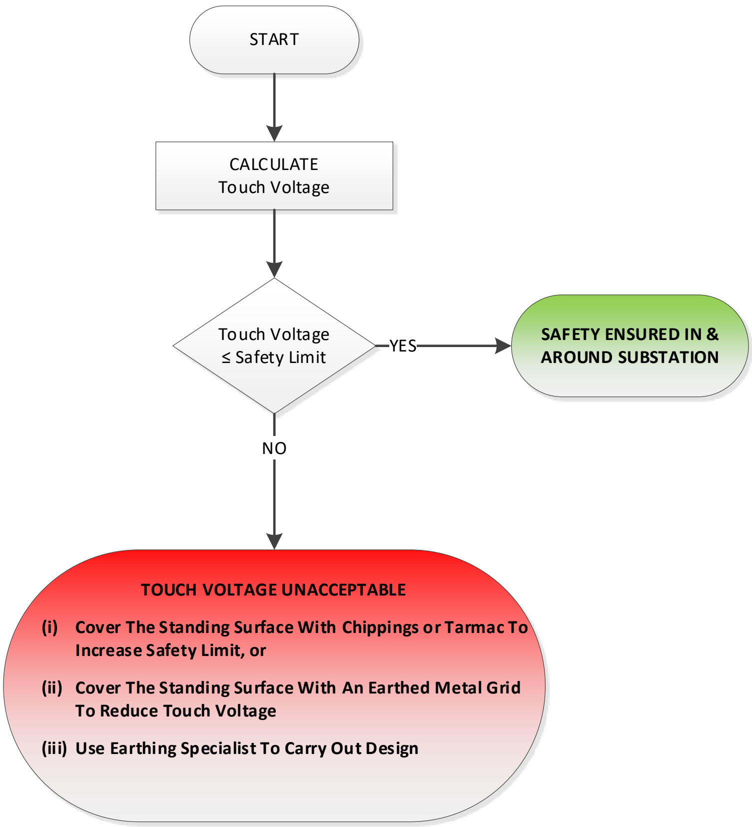
The safety limit for touch voltages for the 'design' earth fault clearance time shall be determined in accordance with Standard Technique TP21A-A.

5.11 DESIGN STEP K: Ensure Safety Inside And Around The Exterior Of The Distribution Substation

5.11.1 Flowchart

The earthing design procedure for ensuring safety inside and around the exterior of the ground mounted distribution substation is shown below.

[16] Tripping time shall be from arc inception to arc extinction



5.11.2 Touch Voltage Assessment

Safety is ensured if the touch voltage is less than, or equal to, the safety limit. The touch voltage (V_{TOUCH}) is calculated by multiplying the 'design' earth potential rise (EPR) by the maximum touch voltage for the substation as a percentage of the EPR ($\%_{TOUCH}$).

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

If the calculated touch voltage is less than the touch voltage safety limit then safety is ensured inside and around the exterior of the ground mounted distribution substation, and the assessment is complete.

If the calculated touch voltage is greater than the touch voltage safety limit then the design is not acceptable and a re-design of the earthing system is required. Possible options include:

- Covering the surface a person stands upon in order to touch earthed conductive parts with a layer of insulating material such as chippings[17] or tarmac in order to increase touch voltage safety limit.

  The insulated surface shall be of sufficient size so that it is impossible to touch the earthed conductive parts with the hand from a standing position off the insulating layer.

[17] The use of chippings is only acceptable in locations where members of the public are excluded. Chippings should not be used in other locations due to the likelihood of the surface covering becoming fragmented and abraded as members of the public walk across it –tarmac should be employed in these locations.

- Covering the surface a person stands upon in order to touch earthed conductive parts with a metal grid[18] which is bonded to those parts in order to reduce the touch voltage.

  The metal grid shall be of sufficient size so that it is impossible to touch the earthed conductive parts with the hand from a standing position off the metal grid.

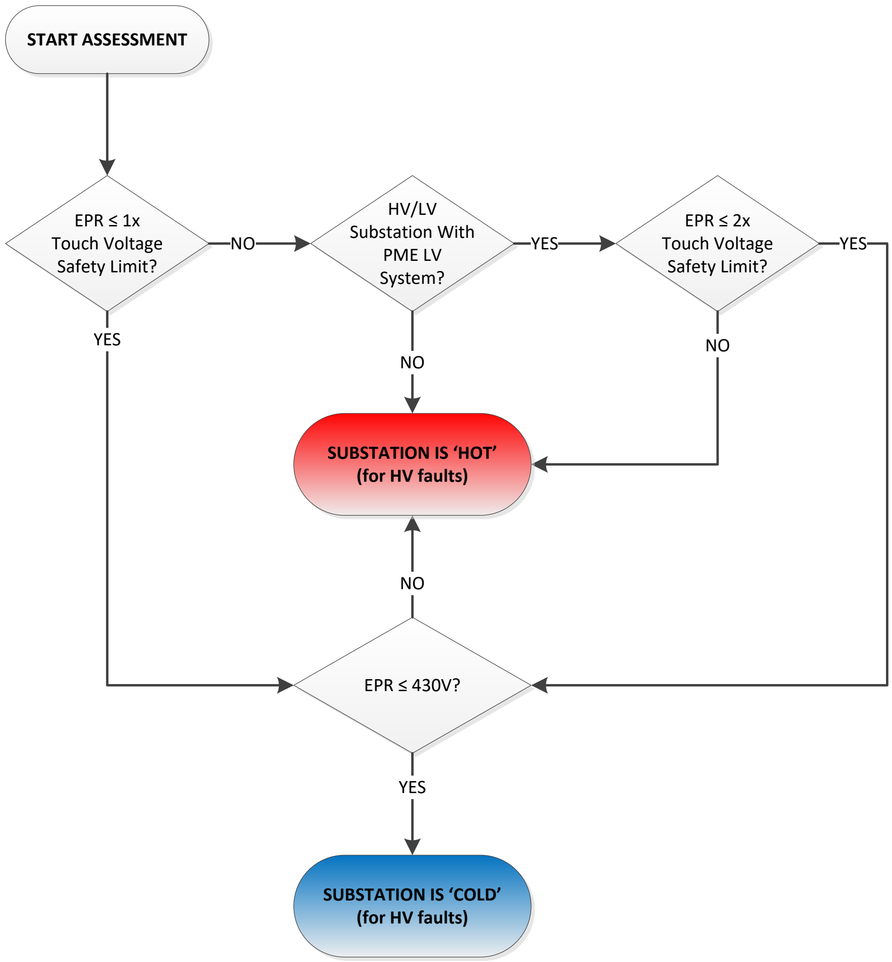
- Employing an Earthing Specialist to model the earthing system and carry out detailed analysis using appropriate and commercially available earthing design software tools

Note that it is also possible to reduce the touch voltage by extending the HV earth electrode in order to reduce its resistance. However, this generally has a limited effect because of the counteracting increase in fault current. In the event that the HV earth electrode is extended, it will be necessary to redo Sections 0 onwards.

5.12 DESIGN STEP L: Determine Whether The Substation Is 'Hot' For HV Faults

5.12.1 Flowchart

The procedure for determining whether the ground mounted distribution substation is a 'hot' or 'cold' site for HV faults (i.e. for faults at the distribution substation itself) is shown below.



18 The use of a metal grid is only acceptable in locations where members of the public are excluded.

5.12.2 Assessment

The ground mounted distribution substation is a 'cold' site (for HV faults) when the following conditions are satisfied:

- The earth potential rise is less than 430V, and
- The earth potential rise is less than 1x the touch voltage safety limit for shoes on soil or outdoor concrete for the HV fault clearance time

  Except where the distribution substation contains an HV/LV transformer whose LV neutral is connected to earth at multiple locations (i.e. a CNE/PME/TN-C LV system) in which case:

  – The earth potential rise is less than 2x the touch voltage limit for shoes on soil or outdoor concrete for the HV fault clearance time

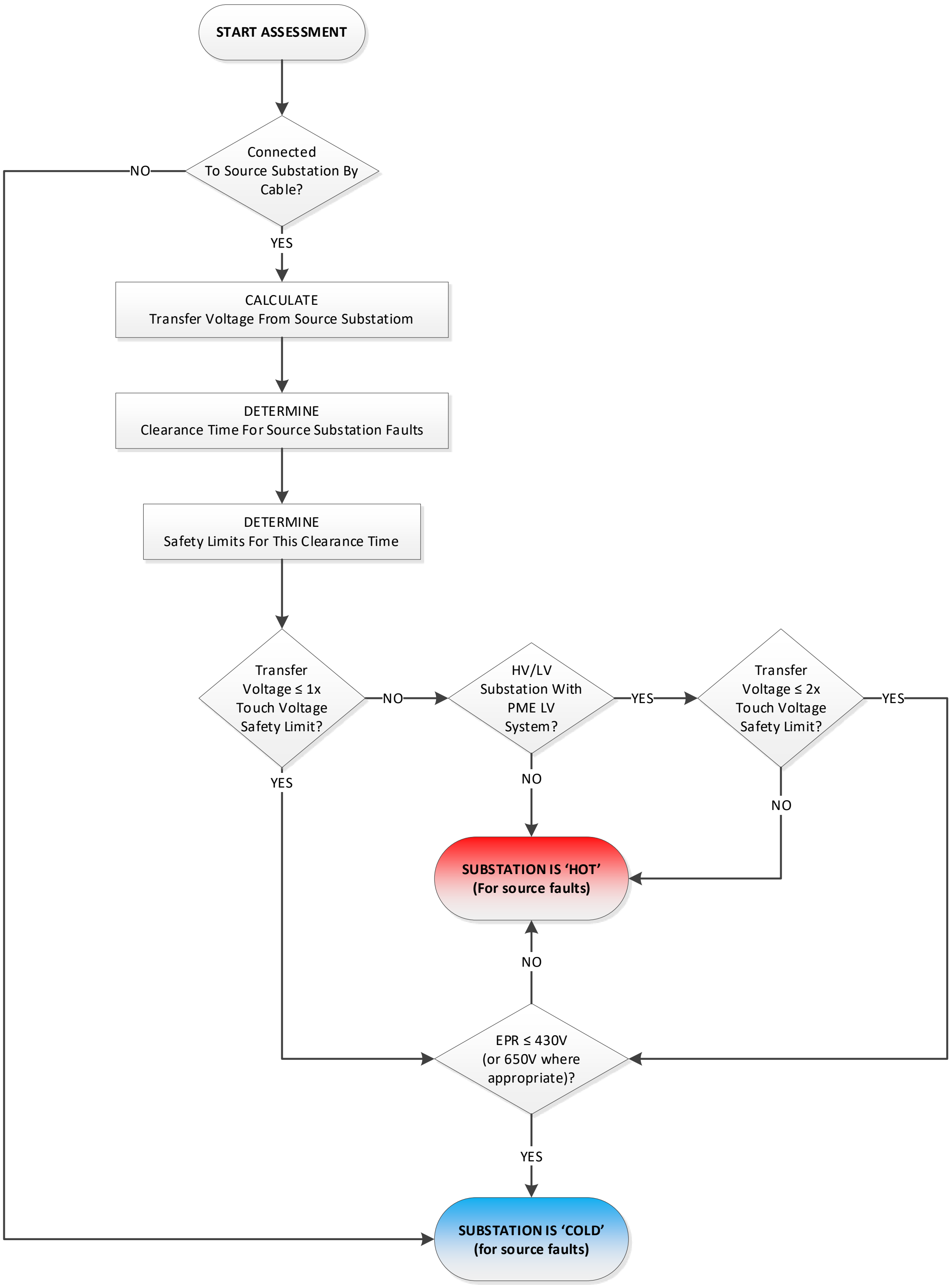
In all other cases the ground mounted distribution substation is a 'hot' site (for HV faults).

The safety limit for touch voltages shall be determined in accordance with Standard Technique TP21A-A and the calculated earth fault clearance time.

5.13 DESIGN STEP M: Determine Whether The Substation Is 'Hot' For Source Substation Faults

5.13.1 Flowchart

The procedure for determining whether the ground mounted distribution substation is a 'hot' or 'cold' site for source substation faults (i.e. for 33kV, 66kV or 132kV faults) is shown below.


START ASSESSMENT
Connected To Source Substation By Cable?
NO
YES
CALCULATE Transfer Voltage From Source Substatiom
DETERMINE Clearance Time For Source Substation Faults
DETERMINE Safety Limits For This Clearance Time
Transfer Voltage ≤ 1x Touch Voltage Safety Limit?
NO
YES
HV/LV Substation With PME LV System?
YES
NO
Transfer Voltage ≤ 2x Touch Voltage Safety Limit?
YES
NO
SUBSTATION IS 'HOT' (For source faults)
NO
EPR ≤ 430V (or 650V where appropriate)?
YES
SUBSTATION IS 'COLD' (for source faults)

5.13.2 Assessment

The ground mounted distribution substation is a 'cold' site for source substation faults when the following conditions are satisfied:

- The voltage transferred from the source substation to the distribution substation is less than 430V, or less than 650V if the 33kV, 66kV or 132kV fault is cleared by high reliability protection with a fault clearance time of less than 200ms, and
- The voltage transferred from the source substation to the distribution substation is less than 1x the touch voltage safety limit for shoes on soil or outdoor concrete for the 33kV, 66kV or 132kV fault clearance time

  Except where the distribution substation contains an HV/LV transformer whose LV neutral is connected to earth at multiple locations (i.e. a CNE/PME/TN-C LV system) in which case:

  - The voltage transferred from the source substation to the distribution substation is less than 2x the touch voltage limit for shoes on soil or outdoor concrete for the 33kV, 66kV or 132kV fault clearance time

In all other cases the ground mounted distribution substation is a 'hot' site for source substation faults.

The transfer voltage from the source substation to the ground mounted distribution substation shall be determined in accordance with Standard Technique TP21A-M.

The clearance time for a 33kV, 66kV or 132kV earth fault at the source substation shall be determined in accordance with Standard Technique TP21A-E.

The safety limit for touch voltage shall be determined in accordance with Standard Technique TP21A-A for the calculated earth fault clearance time.

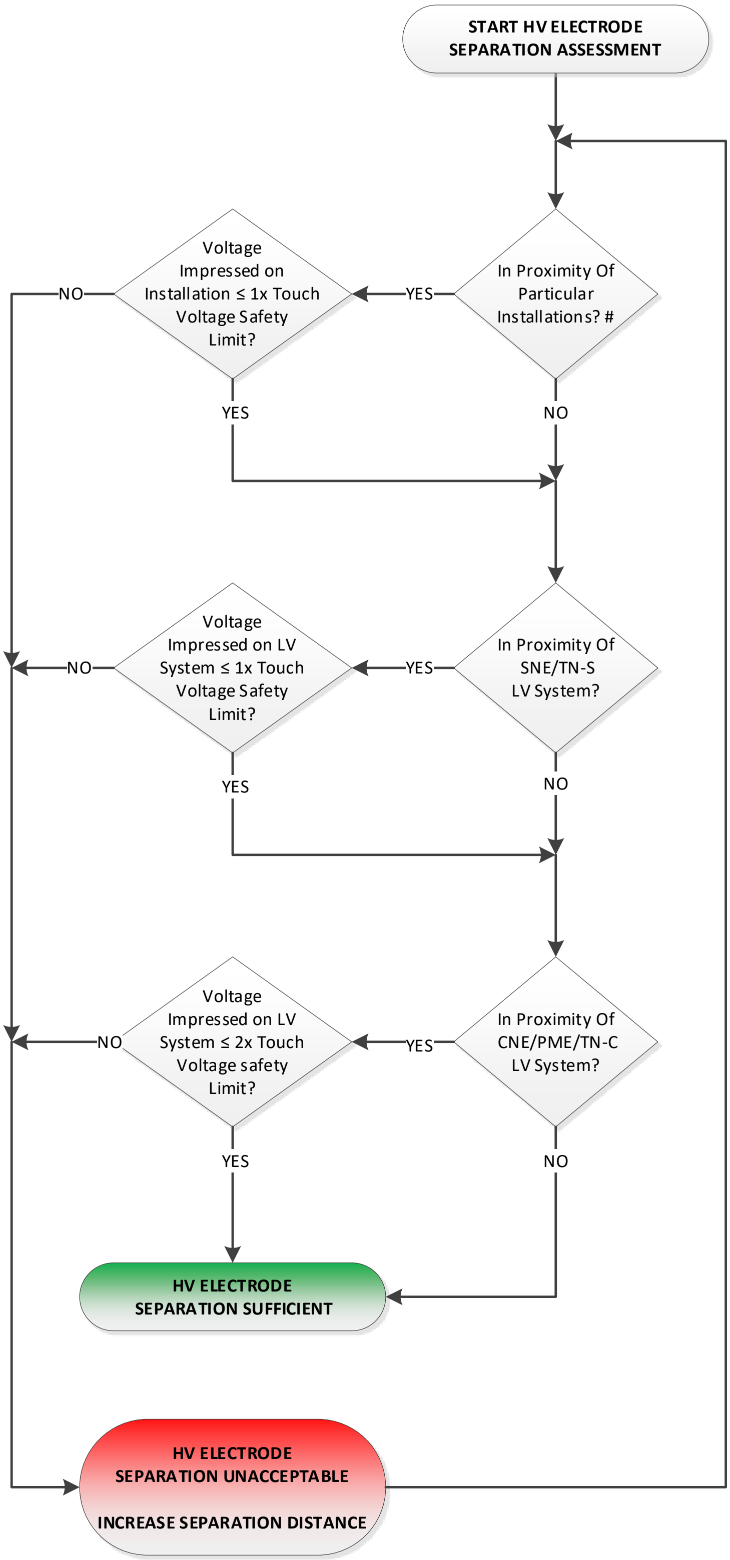
5.14 DESIGN STEP N: Determine Overall 'Hot' or 'Cold' Status Of The Substation

The overall status of the ground mounted distribution substation is 'cold' if the substation is 'cold' for both HV faults and source substation faults.

The overall status of the ground mounted distribution substation is 'hot' if the substation is 'hot' for either HV faults or source substation faults.

5.15 DESIGN STEP O: Determine Separation Distance For HV Electrode

5.15.1 Flowchart



Railway or tramway

Telephone Exchange

Pipeline

Bulk Storage Tank For Petrol or Flammable Liquid

Zoo, Stable, Or Pond/Lake Used For Commercial Fishing

Outdoor Swimming Pool, Paddling Pool Or Shower

Customer TT Electrode

5.15.2 HV Separation Assessment

The HV electrode shall be separated from railways, tramways, telephone exchanges, pipelines, bulk storage tanks for petrol or flammable liquids, zoos, stables, ponds/lakes used for commercial fishing, outdoor swimming pools, outdoor paddling pools, outdoor showers or customer TT electrodes by sufficient distance such that the voltage impressed on those installations in the event of either a HV or source substation fault is not greater than:

- 1x the touch voltage limit for shoes on soil or outdoor concrete for the fault clearance time of the distribution substation or source substation (as appropriate).

The HV electrode shall be separated from WPD, IDNO or Customer LV systems[19] by sufficient distance such that the voltage impressed on the LV system in the event of either a HV or source substation fault is not greater than:

- 2x the touch voltage limit for shoes on soil or outdoor concrete for the fault clearance time of the distribution substation or source substation (as appropriate) where the LV system is connected to earth at multiple locations i.e. a CNE/PME/TN-C LV system
- 1x the touch voltage limit for shoes on soil or outdoor concrete for the fault clearance time of the distribution substation or source substation (as appropriate) where the LV system is connected to earth at a single location i.e. an SNE/TN-S LV system, or a TT LV system

5.16 DESIGN STEP P: Design LV Electrode (Where Relevant)

This step is only necessary for ground mounted distribution substations containing WPD owned HV/LV transformers.

If the entire LV system is confined within the area enclosed by the HV earthing system then a combined HV & LV earth electrode shall be employed even if the distribution substation is a 'hot' site. This situation is likely to occur where a dedicated ground mounted distribution substation provides LV supplies to a substation or power station[20] with an operating voltage of 33kV, 66kV, 132kV, 275kV or 400kV.

Where the LV system leaves the area enclosed by the HV earthing system then separate HV & LV earth electrodes shall be provided where the distribution substation is a 'hot' site as a consequence of either HV or source substation faults.

An LV electrode arrangement shall be selected such that its resistance (excluding network contribution) is as low as is reasonably practicable but not greater than 20Ω for 11kV substations and 15Ω for 6.6kV substations.

[19] Except on Customer LV systems where the Customer elects to combine the HV & LV earths on its HV/LV transformers.

[20] The substation or power station may be owned by WPD, National Grid, another DNO/IDNO, a generator, or a customer.

APPENDIX A

SUPERSEDED DOCUMENTATION

This document supersedes parts of Standard Technique TP21D/3.

APPENDIX B

RECORD OF COMMENT DURING CONSULTATION

No comments received.

APPENDIX C

ANCILLARY DOCUMENTATION

POL: TP21 Fixed Earthing Systems

APPENDIX D

KEYWORDS

Earth; Earthing; Ground; Mounted; Distribution; Secondary; Substation; Design;