

Company Directive

STANDARD TECHNIQUE : TP21B/1

Relating to Design and Installation of Fixed Earthing Systems - Major Substations

Policy Summary

This document defines how 132kV, 66kV and 33kV substation earthing systems shall be designed and installed. It also covers related issues, including special requirements for communication circuits, substation compound fences and LV supplies.

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1.0 INTRODUCTION

- 1.1 Earthing systems influence the safety of personnel, the level of equipment stress and also protection scheme performance. A properly designed and installed substation earthing system is important to safety and system performance.
- 1.2 This document defines how 132kV, 66kV and 33kV substation earthing systems shall be designed and installed. It also covers related issues, including special requirements for communication circuits, substation compound fences and LV supplies.
- 1.3 Engineering Specification [EE SPEC: 89/1](#) specifies requirements for design, installation and commissioning of major substations for use with Invitations to Tender and in Competition in Connections. Reference is made to [EE SPEC: 89/1](#) in this document in order to avoid repeating the same requirements here. Where appropriate, additional guidance is given. Further, as a Distribution Network Operator additional considerations apply over and above those relevant to Invitations to Tender and Competition in Connections - these are included.

2.0 SCOPE

- 2.1 This document covers 132kV, 66kV and 33kV substations.
- 2.2 To avoid substantial duplication, this document makes reference to [EE SPEC: 89/1](#).

3.0 REQUIREMENTS

- 3.1 The requirements of [EE SPEC: 89/1](#) shall apply.

3.1.1 Guidance On Design Process

- 3.1.1.1 The design process for new sites splits into the following stages:
 - a) Obtain site geophysical, electrical and physical data
 - b) Determine equivalent earth structure model
 - c) Determine Substation Earth Impedance, Z_E , model
 - d) Develop substation earthing system layout
 - e) Determine Substation Mesh Earth Electrode Resistance, R_{ES} , based on electrical soil model
 - f) Calculate Substation Earth Impedance, Z_E
 - g) Determine system protection clearance time assuming correct operation
 - h) Calculate substation earth potential rise
 - i) Convert protection clearance time into touch and step voltage limits
 - j) Modify design until touch and step limits are met
 - k) Modify design to avoid hot status or hot zone encompassing nearby buildings, where reasonably practicable
 - l) Verify Substation Earth Impedance, Z_E , low enough to allow satisfactory operation of system protection
 - m) Determine current distribution and select suitable conductor cross-sectional areas

- n) Verify thermal limits of earth electrode not exceeded
- o) Identify impact of potential rise beyond the substation and necessary mitigation

3.1.1.2 With existing sites, the process is similar with the exception that the existing resistance or impedance can be measured.

3.1.1.3 **Site Data**

3.1.1.3.1 The following data is required:

- a) Sufficient soil resistivity data to characterise the site
- b) Where necessary (e.g. rock close to surface) trial pit(s), 0.6m deep, to identify ease of electrode installation
- c) Geotechnical data from any boreholes
- d) Soil type in relation to corrosion of buried copper
- e) Knowledge of constraints on possible earth electrode position
- f) Measurement of impedance/resistance of existing electrode
- g) Location and depth of any existing electrode and other relevant buried apparatus (e.g. metal pipes, pipelines with cathodic protection).
- h) Details of all parallel paths that will form Substation Earth Impedance, Z_E . See section 3.1.1.5.

3.1.1.3.2 [ST:TP21O/2](#) defines the measurement technique for soil resistivity and earth resistance testing.

3.1.1.4 **Equivalent Earth Structure Model**

3.1.1.4.1 See [EE SPEC: 89/1](#) clause 7.1.2.

3.1.1.5 **Substation Earth Impedance Model**

3.1.1.5.1 The earth impedance model of a substation comprises:

- a) Resistance of the local substation electrode, R_{ES}
- b) Parallel impedance of cable(s) with conducting sheath(s) in intimate contact with the ground, Z_{CS1} , Z_{CS2} ... See [ENA Engineering Recommendation S34](#).
- c) Parallel impedance of overhead tower footing resistances connected together by overhead earth wire also known as tower chain impedance, Z_{CH1} , Z_{CH2} ... See [ENA Engineering Recommendation S34](#).
- d) Parallel impedance of remote earthing system(s), Z_{R1} , Z_{R2} ..., connected via insulated sheath cable(s) - series impedance, Z_{S1} , Z_{S2} ...).

3.1.1.5.2 This simplified model assumes the local transformer neutral return path is not included in the substation earth impedance.

3.1.1.5.3 An example is shown in Figure 1.

3.1.1.6 Substation Earthing System Layout

3.1.1.6.1 See [EE SPEC: 89/1](#), clauses 7.2. The substation earth electrode layout can be defined if the position of plinths, control room and compound fence are known. [EE SPEC: 89/1](#), clause 7.9 gives required connectivity and detailed earthing system layout.

3.1.1.6.2 Examples of basic layout are shown in Figures 2 and 3.

3.1.1.6.3 Additional considerations arise for substations containing G.I.S. switchgear and also for those containing air-cored reactors. The special characteristics of such equipment shall be considered in designing the earthing system.

3.1.1.6.4 [ST:SP1BA/1](#) gives detailed standard physical designs for 33/11kV substations, including earthing conductor arrangement on structures.

3.1.1.7 Substation Mesh Earth Electrode Resistance

3.1.1.7.1 See [EE SPEC: 89/1](#), clause 7.3.

3.1.1.8 Substation Earth Impedance

3.1.1.8.1 See [EE SPEC: 89/1](#), clause 7.4. Using the symbols above, the substation earth impedance, Z_E , is given by:

$$Z_E = \left(\frac{1}{R_{ES}} + \frac{1}{Z_{CH1}} + \frac{1}{Z_{CH2}} + \dots + \frac{1}{Z_{CS1}} + \frac{1}{Z_{CS2}} + \dots + \frac{1}{(Z_{R1} + Z_{S1})} + \frac{1}{(Z_{R2} + Z_{S2})} + \dots \right)^{-1}$$

3.1.1.9 System Protection Clearance Time And Earth Fault Current

3.1.1.9.1 System protection clearance times determine the applicable touch and step voltage limits and also applicable telecommunication limit (i.e. the International Telegraph and Telephone Consultative Committee, ITU CCITT, limits used for hot site status and hot zone). The clearance time depends on the fault position, circuit impedance, other impedance seen by the fault current and protection setting. A low fault current with long protection clearance may be more onerous than higher current with faster clearance.

3.1.1.9.2 To determine the limiting conditions various fault positions must be examined. In assessing clearance times and fault currents allowance shall be made for fault path impedance (e.g. substation earth impedance, both local and remote, impedance to earth at remote fault position such as at a remote cable termination after a section of unearthed construction overhead line). No allowance shall be made for fault arc impedance. Two types of fault shall be considered:

- a) Internal fault at substation with fault infeed from remote source transformer neutral(s)
- b) External fault on a circuit out of the substation fed from local transformer neutral(s).

3.1.1.10 Earth Potential Rise

3.1.1.10.1 See [EE SPEC: 89/1](#), clause 7.6

3.1.1.11 Touch And Step Voltage Limits

3.1.1.11.1 [ST:TP21A/2](#) defines touch and step voltage limits by fault clearance time.
See Figure 13.

3.1.1.12 Modifications To Reduce Touch And Step Voltages

3.1.1.12.1 Reduction of both touch and step voltages is achieved if the Earth Potential Rise (EPR) is reduced. Options for reducing the EPR include:

- a) Internal fault at substation with fault infeed from remote source transformer neutral(s):
 - 1) Increasing source impedance
 - 2) Increasing source neutral earthing impedance
 - 3) Increasing source earth impedance
 - 4) Reducing Substation Earth Impedance, Z_E , by connection of other parallel paths
 - 5) Reducing Substation Mesh Earth Resistance, R_{ES} , by increasing the area enclosed or using rods penetrating lower resistivity soil
 - 6) Reducing the current flowing into the substation earth impedance, I_E , by connection of mutually coupled conductors (e.g. continuous tower earth wires or cable sheaths) back to source.
- b) External fault on a circuit out of the substation fed from local transformer neutral(s):
 - 1) Increasing source impedance
 - 2) Increasing local neutral earthing impedance
 - 3) Reducing Substation Earth Impedance, Z_E , by connection of other parallel paths
 - 4) Reducing R_{ES} by increasing the area enclosed or using rods penetrating lower resistivity soil
 - 5) Reducing I_E by connection of mutually coupled conductors (continuous tower earth wires or cable sheaths) back to source
 - 6) Allowing for fault impedance (excluding fault arc impedance).

3.1.1.12.2 Reduction of touch and step potentials is also achieved by making the earth electrode system electrically similar to a large horizontal conducting plate. This is achieved by increasing the mesh density (i.e. reducing the spacing between parallel electrodes in the mesh) or addition of earth electrode in areas of concern.

3.1.1.12.3 Reducing the depth of the earth electrode reduces touch potential and increases step potential. However, a minimum depth of 0.5m applies to conductors included in calculating R_{ES} to minimise variation should surface soil freeze.

- 3.1.1.12.4 Where touch voltage limits are exceeded at nearby buildings it may be necessary to enclose them within the substation earth electrode.
- 3.1.1.12.5 Compliance with the voltage limits shall be achieved where possible using the above methods. Where this cannot be achieved the following options shall be considered:
- a) Raise the allowable voltage limits by using faster earth fault clearance
 - b) Use of high resistivity ground surface covering *outside* the fence.

3.1.1.13 Modifications to Avoid Hot Status

- 3.1.1.13.1 The measures described above to reduce EPR will also help avoid a substation being classified as 'hot' if the EPR can be brought below the ITU CCITT limits (i.e. 430V or, under certain conditions, 650V). It may be possible to avoid hot status by use of the higher ITU CCITT limit if protection clearance times can be reduced to meet the criteria defined in [EN 50163:2006](#).

3.1.1.14 Modifications to Limit Hot Zone

- 3.1.1.14.1 Reduction of the overall hot zone of a hot substation is achieved by reducing the EPR. See above.
- 3.1.1.14.2 Changes in the shape of the hot zone are achieved by altering the earth electrode geometrical layout. It may be possible to avoid the hot zone enclosing buildings by suitable changes to the electrode layout.
- 3.1.1.14.3 Alternatives are also possible, including relocating the substation or nearby buildings.

3.1.1.15 Protection Performance

- 3.1.1.15.1 As the Substation Earth Impedance, Z_E , limits earth fault current it is necessary to verify that there is sufficient fault current for circuit end faults. Where this is not achieved, options include:
- a) Reducing Z_E
 - b) Reducing circuit impedance
 - c) Reduction of neutral earthing device impedance.

3.1.1.16 Selection Of Earthing System Component Size And Materials

- 3.1.1.16.1 See [EE SPEC: 89/1](#), clauses 7.10 through 7.14.
- 3.1.1.16.2 The distribution of fault current I_E into the parallel impedances which make up Z_E depends upon the relative impedance of each component. The current rating of each path parallel with R_{ES} shall be checked to ensure it can carry the fault current for the time specified in [EE SPEC: 89/1](#), clause 6.1.3. The distribution of fault current I_{ES} into the substation earth mesh shall also be checked.

3.1.1.16.3 [EE SPEC: 89/1](#) clause 7.14.5 defines requirements that ensure thermal limits of buried earth electrode are met. If difficulty is encountered in meeting the limits the following options shall be considered to increase the total surface area:

- a) Increase total length
- b) Increase conductor dimensions
- c) Use strip instead of stranded conductor.

3.1.2 Additional Issues

3.1.2.1 Power Cable Sheath Earthing

3.1.2.1.1 See [EE SPEC: 89/1](#) clause 7.15.1. NB If the single-core cable length does not exceed 25m then it can be assumed that the 50V limit is met. In other cases consult Primary System Design.

3.1.2.1.2 With reference to [EE SPEC: 89/1](#), clause 7.15.1.3, examples of permitted arrangements for transformer neutral cable sheaths are shown in Figure 16:

- a) Neutral cable sheath unearthed at CT end. See Figures 16a and 16b.
- b) Neutral cable sheath unearthed at one end with sheath insulated from earth along its length. See Figures 16c and 16d (also Figures 16a and 16b).
- c) Neutral cable sheath earthed at both ends with connection to earth at CT end taken back through CT. See Figures 16e and 16f.

3.1.2.1.3 Figure 17 shows the permitted method employed with power cables.

3.1.2.2 Fences and Gates

3.1.2.2.1 See [EE SPEC: 89/1](#), clause 7.15.3 and also [ST:TP21K](#).

3.1.2.3 Stays

3.1.2.3.1 See [EE SPEC: 89/1](#), clause 7.15.4. The various arrangements are shown in Figures 4 through 7.

3.1.2.4 Surge Arresters

3.1.2.4.1 See [EE SPEC: 89/1](#), clause 7.15.5.

3.1.2.4.2 [ST:TP21S/1](#) defines how surge arresters shall be applied to grid transformers. It covers surge arrester positioning and explains associated earthing arrangements.

3.1.2.5 LV Supplies to Major Substations

3.1.2.5.1 See [ST:SD3A](#).

3.1.2.5.2 The preferred arrangement is for LV supplies to major substations to be dedicated to that function, without supplies to customers external to the substation. This avoids transfer potentials to customers' installations and simplifies design.

3.1.2.5.3 Where the LV supply is derived from a transformer outside of the earth 'mesh/grid' it is necessary to control transfer potentials.

3.1.2.5.4 Permitted arrangements are as follows:

- a) Protective neutral bond (PNB) via dedicated auxiliary (or earthing) transformer located within 'mesh/grid'
- b) Protective neutral bond (PNB) via dedicated pole-mounted auxiliary transformer located outside the 'mesh/grid'
- c) Protective neutral bond (PNB) via dedicated ground-mounted auxiliary transformer located outside the 'mesh/grid'
- d) Protective multiple earth (PME) via local LV network
- e) TN-S systems (separate neutral and protective conductors throughout i.e. cable sheath return or separate aerial earth) via local LV network.

3.1.2.5.4.1 Protective Neutral Bond (PNB) Via Dedicated Auxiliary (Or Earthing) Transformer Located Within 'Mesh/Grid'

3.1.2.5.4.1.1 This provides a dedicated supply to the major substation. The LV neutral is connected to the substation earthing system via the auxiliary transformer HV metalwork earth. If the auxiliary transformer is ground-mounted, the transformer shall have potential grading electrode. See Figure 8.

3.1.2.5.4.2 Protective Neutral Bond (PNB) Via Dedicated Pole-mounted Auxiliary Transformer Located Outside The 'Mesh/Grid'

3.1.2.5.4.2.1 This provides a dedicated supply to the major substation. The LV neutral is connected to the substation earthing system. The auxiliary transformer HV metalwork is earthed via:

- a) The major substation earthing system via PVC/PVC insulated conductor (see Figure 9a), or
- b) A separate local HV earth separated from the major substation earth electrode by a minimum of 2m. See Figure 9b.

3.1.2.5.4.2.2 Note that the transformer in arrangement a) above may be more vulnerable to lightning damage because of the lead length to the earth electrode.

3.1.2.5.4.2.3 The arrangement in b) above shall not be used where the major substation rise of potential may exceed 3kV RMS; consult Primary System Design.

3.1.2.5.4.3 Protective Neutral Bond (PNB) Via Dedicated Ground-mounted Auxiliary Transformer Located Outside The 'Mesh/Grid'

3.1.2.5.4.3.1 This provides a dedicated supply to the major substation. The LV neutral is connected to the substation earthing system. The auxiliary transformer HV metalwork is earthed via:

- a) The major substation earthing system via PVC/PVC insulated conductor (see Figure 10a), or
- b) A separate local HV earth separated from the major substation earth electrode by a minimum of 2m. See Figure 10b.

3.1.2.5.4.3.2 In the case of a) above a potential grading electrode may be required around the ground-mounted transformer to control touch potential adequately. As this will affect the hot zone, if present, and touch/step voltages the design of this must be considered as part of overall major substation earthing system design.

3.1.2.5.4.3.3 The arrangement in b) above shall not be used where the major substation rise of potential may exceed 3kV RMS; consult Primary System Design.

3.1.2.5.4.4 Protective Multiple Earth (PME) Via Local LV Network

3.1.2.5.4.4.1 Provision of an LV supply from a PME system requires connection of the neutral and earth at the intake position. To prevent local potential differences, the LV earth shall be connected to the substation earthing system. This creates two problems when an earth fault occurs with a subsequent earth potential rise:

- a) Current flow to remote PME earth electrodes
- b) Voltage rise on PME neutral-earths.

3.1.2.5.4.4.2 The voltage rise may cause touch voltage hazards (e.g. metalwork and telephones) at customers' premises and stressing of customers' equipment if this has a different earth reference (e.g. modems, cordless telephones etc).

3.1.2.5.4.4.3 To control these problems, this type of supply shall only be permitted where the earth potential rise does not exceed:

- a) 430V RMS
- b) Appropriate touch voltage limit

whichever is lower. See Figure 11. However, the 430V limit can be exceeded if all communication equipment is appropriately protected subject to touch voltage limits. See section 3.1.3.5.

3.1.2.5.4.5 TN-S Systems (Separate Neutral And Protective Conductors Throughout) Via Local LV Network

3.1.2.5.4.5.1 The LV earth transfers the remote earth reference to the substation if it is not connected to the major substation earthing system. To control this the LV earth shall be connected to the major substation earthing system. This creates the same problems as experienced with PME above. To control these problems, this type of supply shall only be permitted where the earth potential rise does not exceed:

- a) 430V RMS

b) Appropriate touch voltage limit

whichever is lower. See Figure 12. However, the 430V limit can be exceeded if all communication equipment is appropriately protected subject to touch voltage limits. See section 3.1.3.5.

3.1.2.6 Control Of Potential Rise Impact Outside Substation

3.1.2.6.1 The restrictions applying to cases of customer LV supplies common with major substation LV supplies are covered above. Communication circuit and water service requirements at hot substations are covered under [EE SPEC: 89/1](#), clauses 8.11 and 8.12.

3.1.2.6.2 The following additional problems can arise and shall be controlled:

- a) Transfer of potential along insulated sheath power cables (e.g. CAS, XLPE and Triplex types)
- b) Voltage rise on LV earth electrodes outside the substation during earth faults due to resistive coupling.

3.1.2.6.3 Transferred Potential Along Insulated Sheath Power Cables

3.1.2.6.3.1 Insulated sheath power cables can transfer the potential from one point to another. See Figures 14 and 15. This may cause touch voltage hazards at remote exposed metalwork (e.g. ground mounted distribution transformers) that shall be controlled to safe levels. Options for elimination of the problem include:

- a) Insert a section of overhead line.
- b) Insert a sufficient length of non-insulated sheath cable (e.g. PILCSWA). This permits current to flow into the ground, giving a voltage drop, and reduces the transferred potential.
- c) Reduce the resistance of the remote earthing system. This causes current to flow to the remote earth and the subsequent voltage drop along the sheath reduces the transferred potential.

3.1.2.6.3.2 Where these methods are not appropriate, it may be necessary to control the touch voltage by addition of potential grading electrode around the affected plant (and with connection to the plant). Furthermore, separation of distribution transformer HV and LV earths may also be required.

3.1.2.6.4 Voltage Rise on LV Electrodes by Resistive Coupling

3.1.2.6.4.1 The voltage rise in the soil around a major substation which is subject to earth potential rise can appear on nearby LV earth electrodes via resistive coupling without direct electrical connection (i.e. *without* the LV system supplying both major substation and nearby customers).

3.1.2.6.4.2 The voltage rise may exceed ITU CCITT limits, above which telecommunication operators (e.g. BT) require line isolation equipment to be fitted.

- 3.1.2.6.4.3 By notifying telecommunication operators which sites are hot and the extent of the hot zone, this problem is controlled. Section 3.1.3.5 refers. Should customers/developers ask for advice on how close they can develop near a major substation this should be referred to Primary System Design.

3.1.3 Installation

- 3.1.3.1 See [EE SPEC: 89/1](#), clause 8.

3.1.3.2 Joints

- 3.1.3.2.1 [ST:TP21L/1](#) details jointing methods.

3.1.3.3 Soil Around Earth Electrode

- 3.1.3.3.1 See [EE SPEC: 89/1](#), clause 8.4. In particularly hostile soil, other measures may be required and reference shall be made to Primary System Design.

3.1.3.4 Addition of Metal Plant and Equipment

- 3.1.3.4.1 See [EE SPEC: 89/1](#), clause 8.8 in conjunction with [ST:TP21K](#). Primary System Design shall be consulted prior to the change.

3.1.3.5 Protection of Communication Circuits at Hot Sites

- 3.1.3.5.1 Primary System Design shall notify relevant telecommunication operators of major substations that are classified as hot.

4.0 BACKGROUND

4.1 Equivalent Earth Structure Model

- 4.1.1 Generally, for earthing design purposes, soil structures in the WPD area are non-uniform and horizontally layered.
- 4.1.2 The soil resistivity field data is used to determine the equivalent earth structure model. The number of points of inflexion in a graph of measured apparent resistivity against probe spacing indicates the number of layers. Use of specialist software permits the layer resistivity and thickness to be determined.

4.2 Telecommunications Equipment and Hot Sites

- 4.2.1 Telecommunications services to substations and nearby buildings are generally via insulated metallic circuits. Consequently, should a rise of earth potential occur the telecommunication circuit can cause a transfer potential. Clearly, this may be hazardous to personnel and may cause equipment withstand levels to be exceeded.
- 4.2.2 Telecommunications operators employ protective measures if the rise of earth potential exceeds the ITU CCITT limits of 430V and 650V. The latter figure applies if high reliability substation protection relays would act to clear the

associated fault. Major substations where the potential rise exceeds the ITU CCITT limits are known as 'hot sites'.

- 4.2.3 [ENEA Engineering Recommendation S36/1](#) defines the nationally agreed procedure to identify and record 'hot sites'.

4.3 **Approved Materials**

- 4.3.1 Considerations in selection of materials for earthing systems include:

- a) Conductivity
- b) Corrosion performance
- c) Mechanical performance
- d) Installation cost
- e) Ease of installation
- f) Theft.

- 4.3.2 Overall, copper is judged to give the best performance and is suitable for use above or below ground. Aluminium gives good performance above ground but is not suitable for use below ground because of its corrosion performance.

- 4.3.3 Flexible conductor is required where bonding across moving parts (e.g. at gates and metal doors).

4.4 **Sizes - Earthing Conductors**

- 4.4.1 The rating of an above-ground conductor is determined by:

- a) Cross-sectional area
- b) Permissible temperature rise
- c) Fault duration
- d) Constants specific to the material.

- 4.4.2 [ENEA Technical Specification 41-24](#) recommends rating based on ultimate 3-phase symmetrical fault current. However, this generalisation will tend to undersize for 132kV substations as with 132kV the single-phase to earth fault current may exceed the three-phase level. It is considered appropriate to take account of this in selecting the associated earthing conductors.

- 4.4.3 The minimum size of fence earthing conductor takes account of the possibility of an overhead conductor falling onto a metal substation fence.

4.5 **Sizes - Bonding Conductors**

- 4.5.1 Conductors that are not likely to carry fault current do not need to be as large as other earthing conductors. An example is the bond to ancillary metalwork. In such cases, the minimum of 50mm² given in BS 7430 has been adopted. However, for bonds that may be subject to movement a compromise is necessary (i.e. gate-gatepost bonds) and a minimum of 35mm² copper equivalent has been accepted.

4.6 Sizes - Earth Electrode

- 4.6.1 Consideration of mechanical and corrosion performance leads to the 70mm² minimum cross sectional area and, for copper tape, the 3mm thickness limit.
- 4.6.2 With interconnected grid earth electrode there are multiple paths for fault current. Spur connections from earthing conductor that may carry fault current need to be fully rated. Connections between single-phase switchgear (if used) need to be fully rated to account for three single-phase earth faults. Other mesh/grid electrode is rated to 60% of full fault current which is the principle given in BS 7354.

4.7 Joints

- 4.7.1 The method of jointing can de-rate a conductor. BS 7430 defines acceptable maximum temperatures by joint type. [ENA Technical Specification 41-24](#) gives maximum temperatures for copper and aluminium of 405 °C and 325 °C respectively. These are lower than the limits given in BS7430 for welded and brazed joints and therefore these types of joint do not de-rate earth conductor/electrode. With bolted and crimped joints a limit of 250 °C applies and effectively de-rates to 69% of nominal for copper and 81% for aluminium. See [EE SPEC: 89/1](#), Table C3.
- 4.7.2 It is considered undesirable to de-rate conductor sized on prospective fault current by the jointing method. Therefore, brazed and welded are preferable and this is recognised in the Policy.
- 4.7.3 Bolted joints are not permitted below ground level because of their corrosion performance.

4.8 Earthing System Layout

- 4.8.1 The general physical arrangement of an interconnected grid encompassing all metal plant is aimed at:

- a) Minimising touch voltage on plant and equipment
- b) Equalising potential gradient across the site.

However, in practice economic considerations limit what can be achieved (i.e. how dense the earth mesh is) and it is satisfactory simply to ensure the safety voltage limits and other minimum requirements are met.

- 4.8.2 Earth rods provide some immunity against seasonal effects (e.g. changes in moisture content).
- 4.8.3 The flow of high fault current through unintended paths (e.g. multicore sheaths) can cause extensive damage. To help prevent this the Policy calls for duplication of critical connections.
- 4.8.4 Metalwork that can be touched simultaneously (hand-to-hand) but is not directly bonded together can present an electric shock hazard that can be controlled by bonding, shrouding or physical separation.

4.9 Depth

- 4.9.1 The resistance of an earth electrode increases markedly when the soil around it freezes. To avoid the effect of this it is necessary to install earth electrodes at a depth of around 0.5m or more. Electrode performing a bonding or earth mat function need not be installed so deep subject to step voltages being satisfactory. Electrode installed where ploughing may occur is considered safe from damage when installed 1.0m deep.

4.10 Soil

- 4.10.1 Buried earth electrode is subject to corrosion. The rate of corrosion depends on a number of factors, including:

- a) Chemical nature of the soil
- b) Acidity
- c) Salt content
- d) Differential aeration
- e) Presence of anaerobic bacteria.

- 4.10.2 Of particular concern are the most aggressively corrosive soils. These include soil with cinders, peaty soil and some clays, poorly drained soils and those with a low resistivity.

4.11 Chippings

- 4.11.1 Use of high resistivity chippings effectively raises the tolerable step and touch voltages at a site. This arises because of the increased impedance to flow of current through the body. See [ST:TP21A/2](#).

4.12 Fences and Gates

- 4.12.1 Whichever method of earthing of a substation fence is employed, a touch voltage will arise under earth fault conditions. This is highest when the fence is connected to the substation earthing system with no potential grading. Use of a perimeter potential grading electrode permits a much higher grid potential rise before the touch voltage limit is exceeded.

- 4.12.2 A hand-to-hand touch voltage hazard may exist between metalwork that can be energised to different potentials. Examples include across:

- a) Substation gates
- b) Fence panels with poor electrical connection
- c) Remotely earthed external fence and compound fence
- d) Internal fence and compound fence with poor electrical connection.

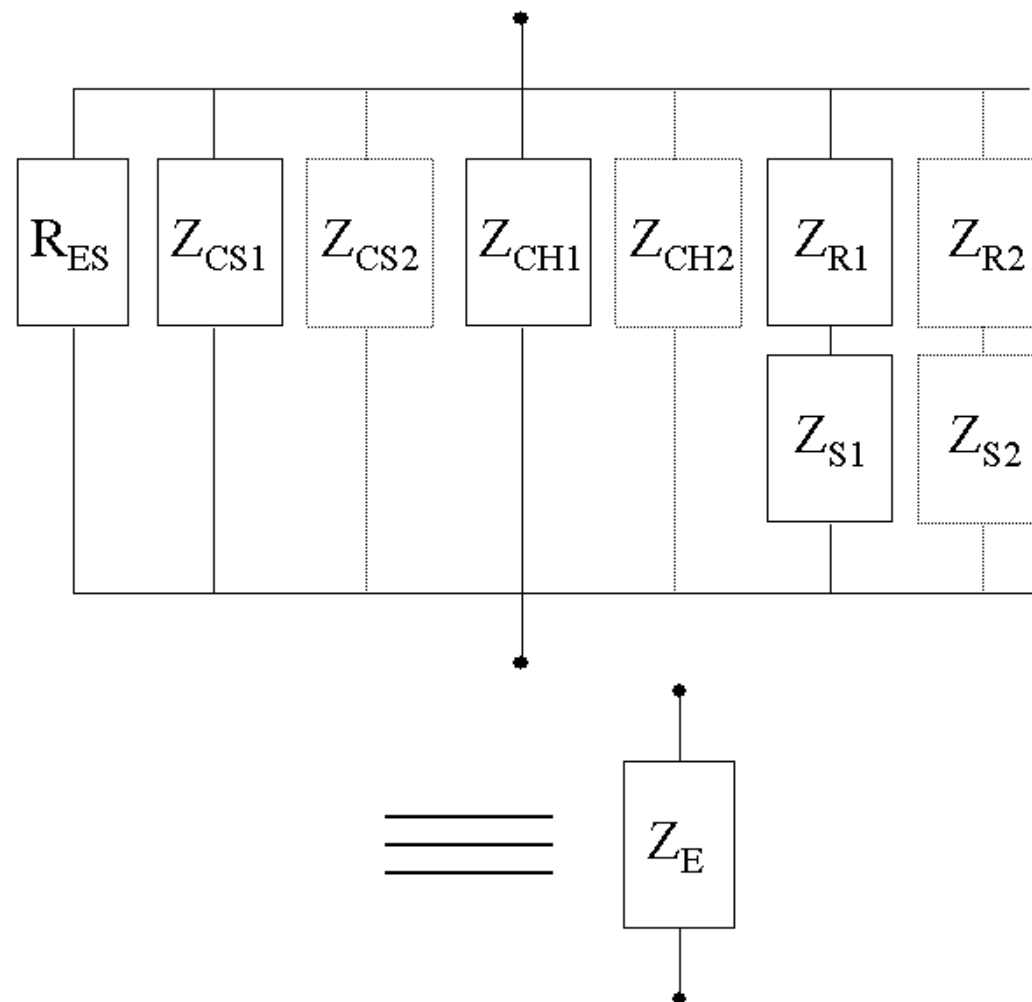


Figure 1 Example substation earth impedance model

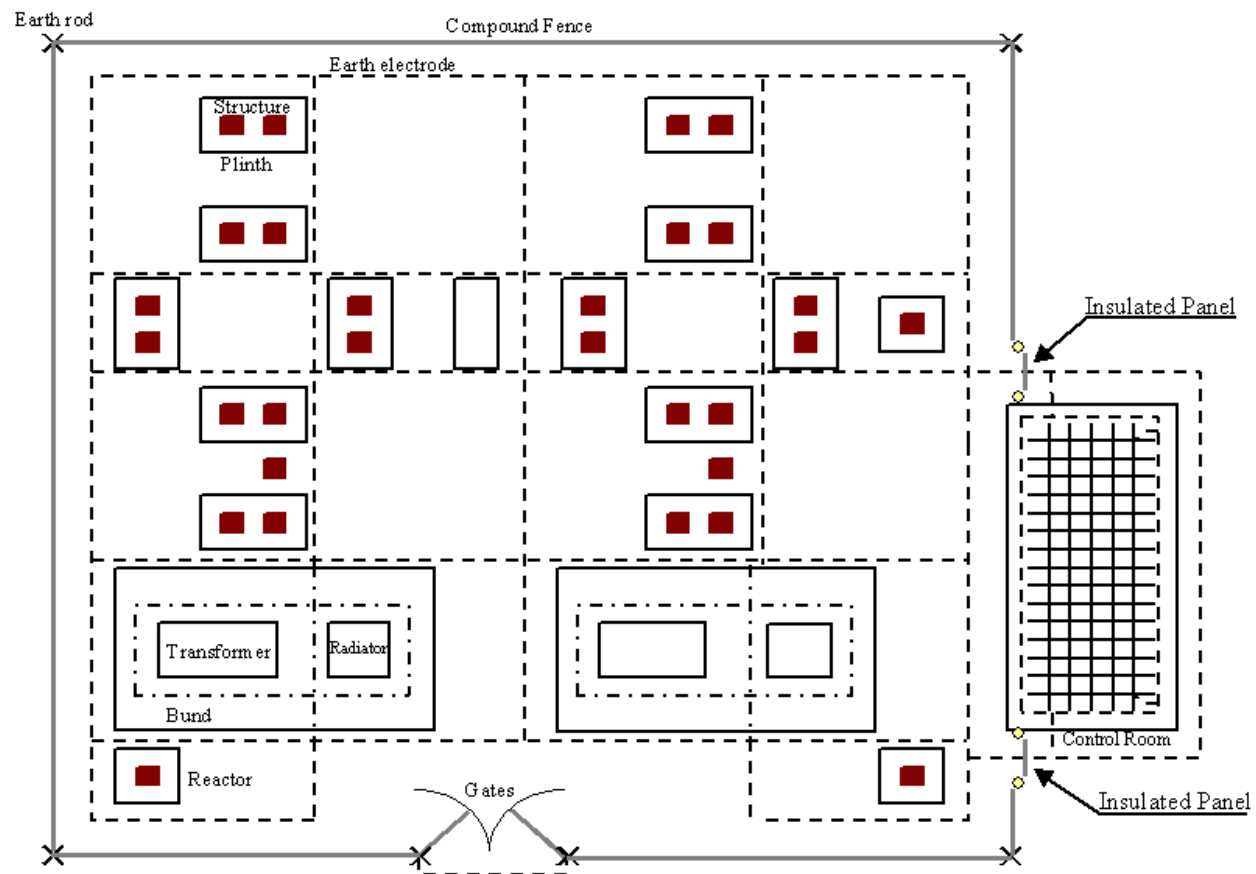


Figure 2 Example Earth Electrode Layout - Independently Earthed Fence

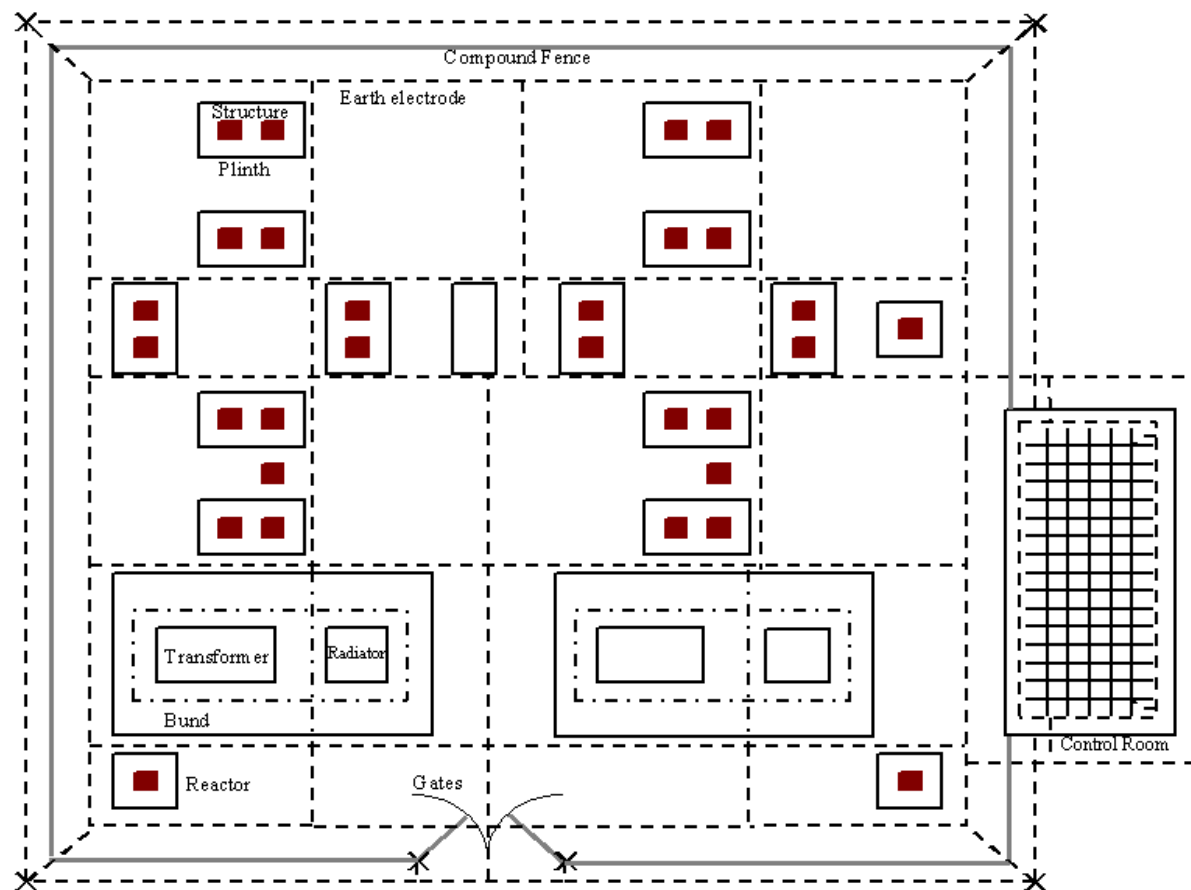


Figure 3 Example Earth Electrode Layout - Fence Earthed Via Substation Earthing System

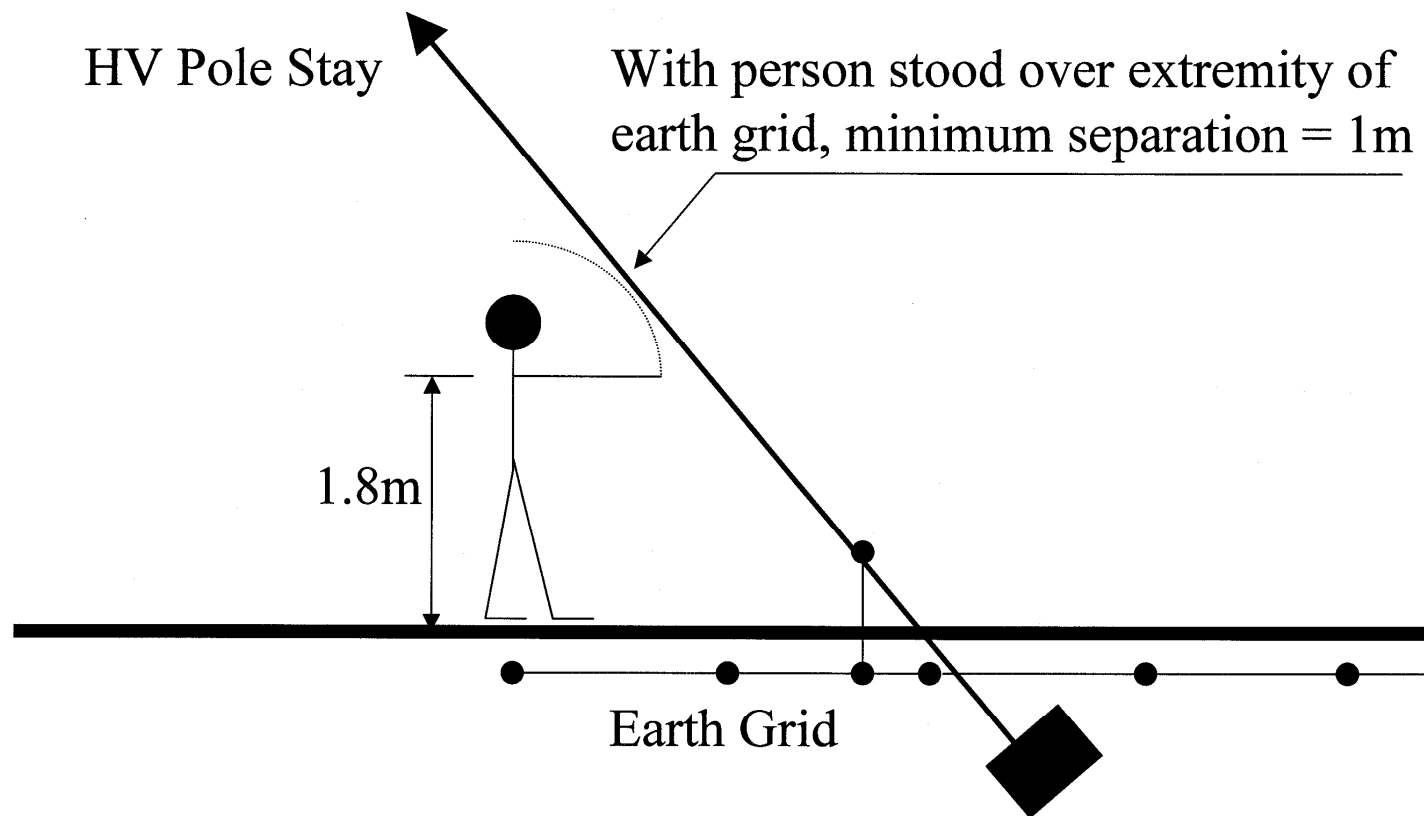


Figure 4 Pole Stay within Substation Earth Grid

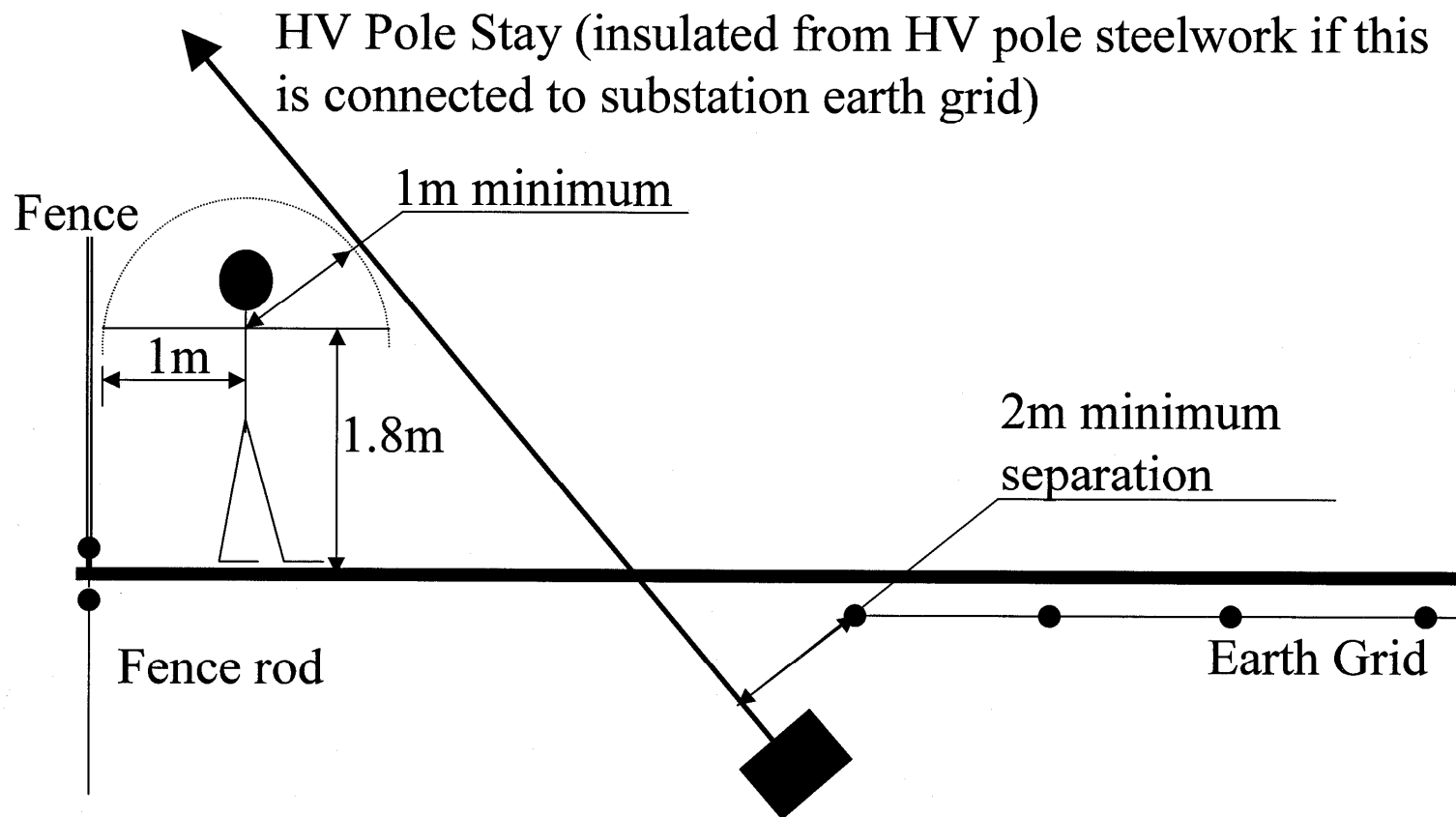


Figure 5 Pole Stay Effectively Separated From Equipment Which Can Attain A Different Potential

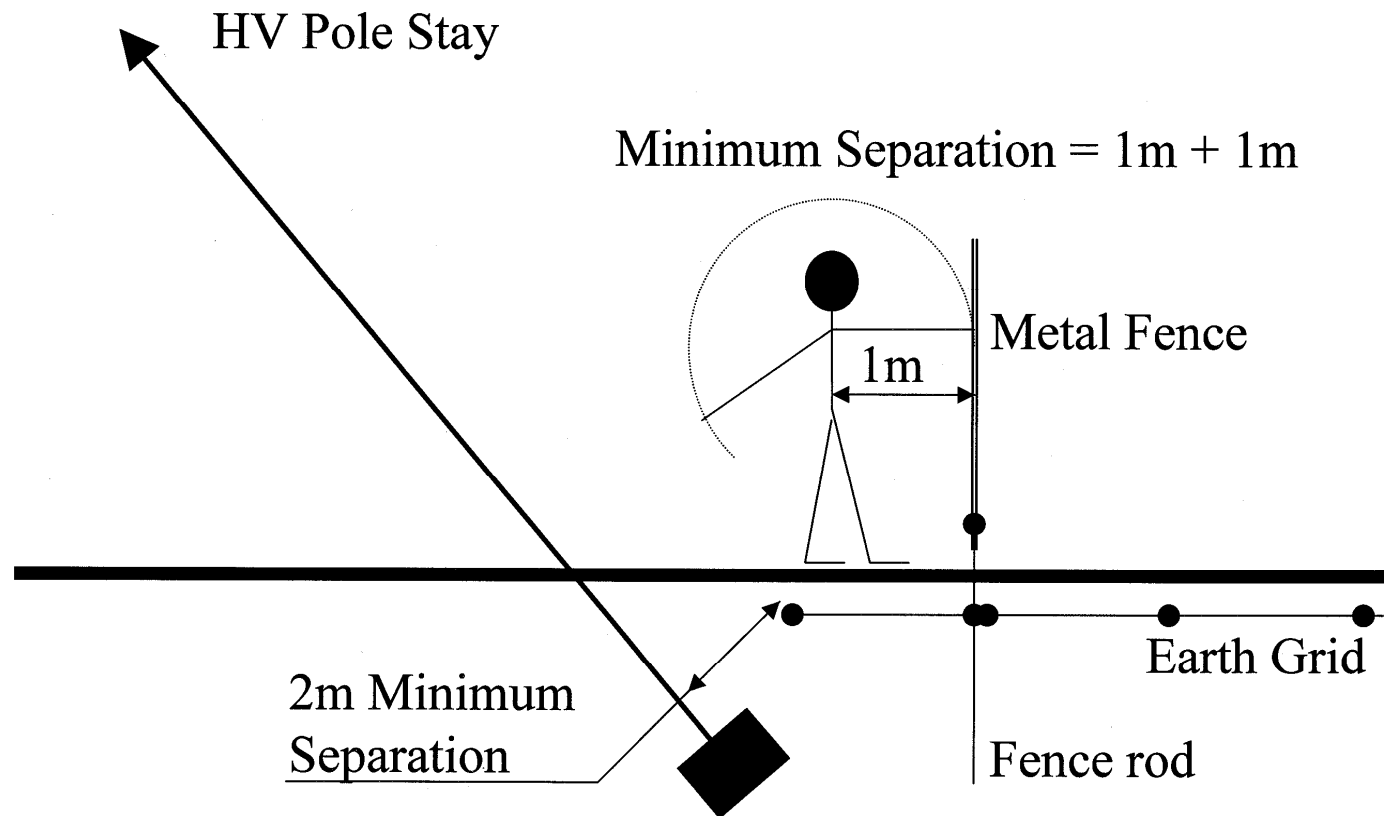


Figure 6 Pole Stay Effectively Separated From Equipment Which Can Attain A Different Potential

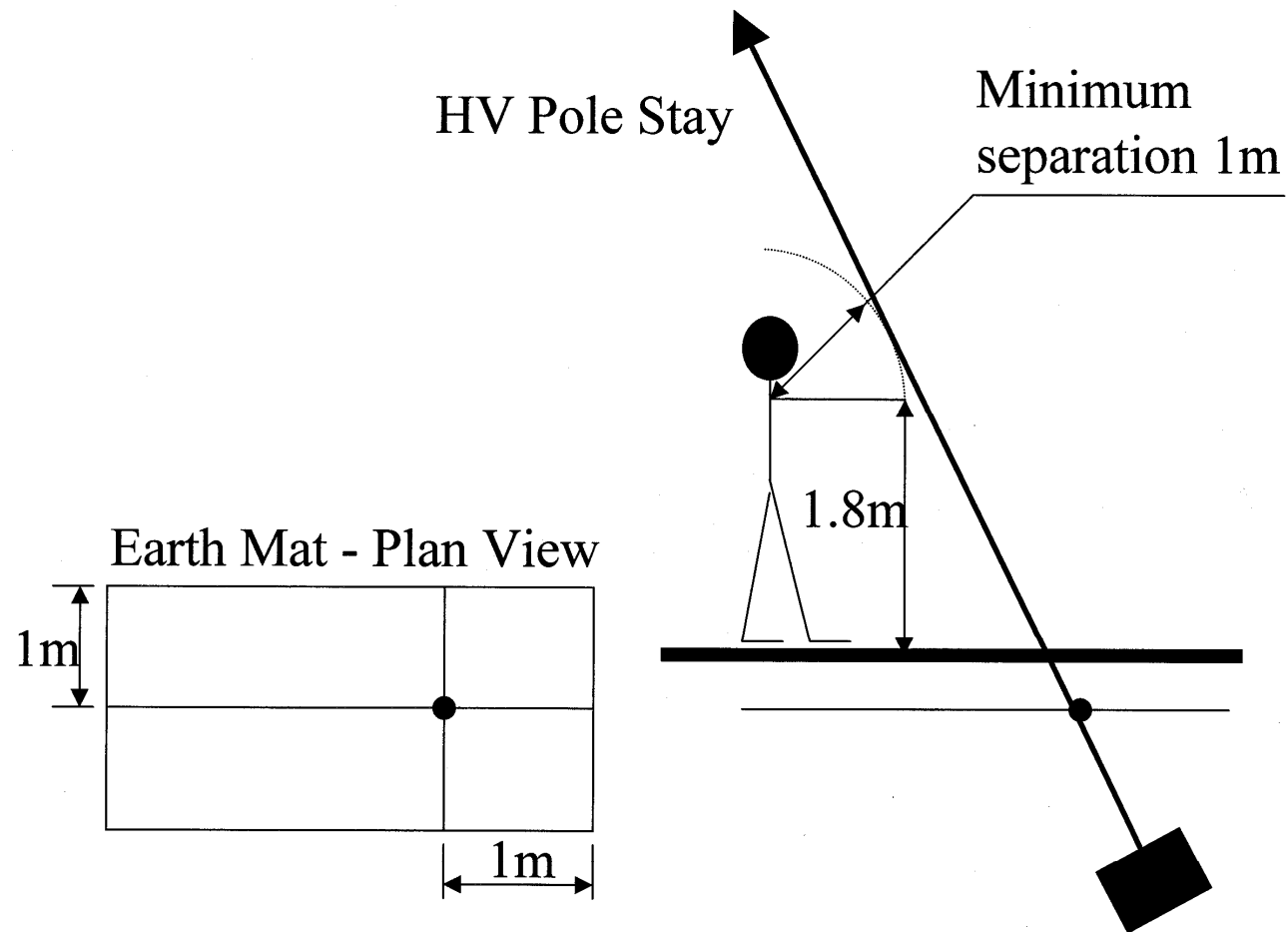
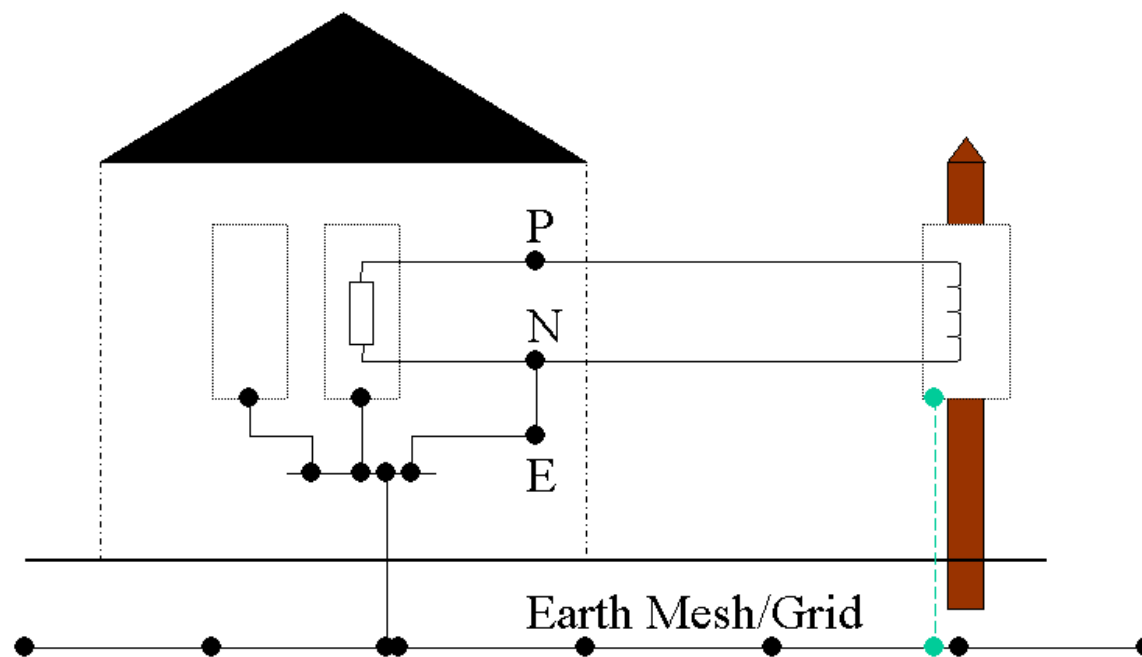


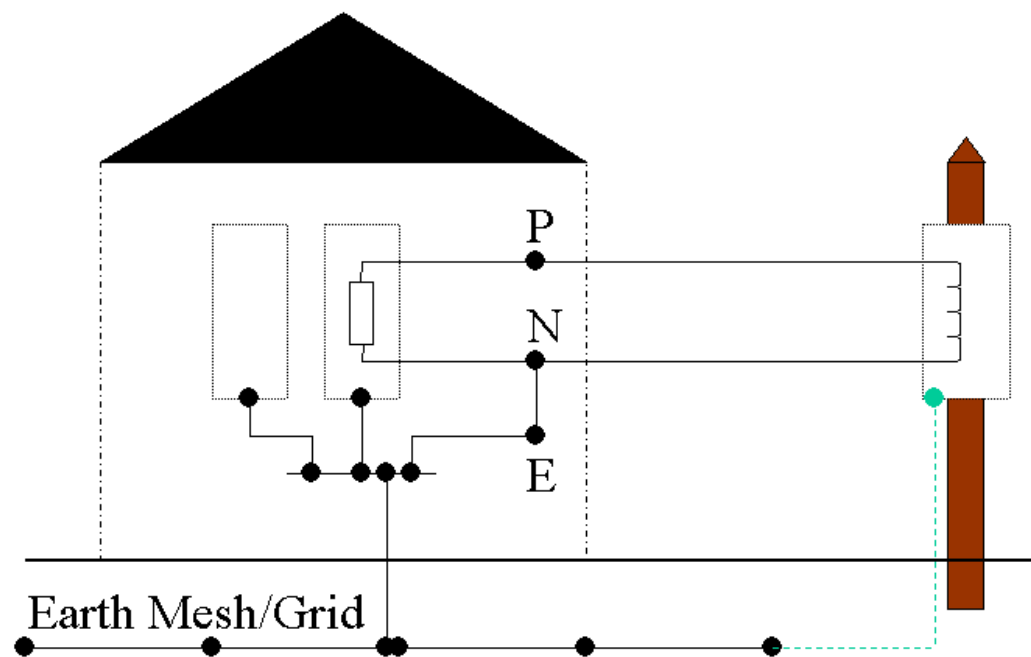
Figure 7 Control of Pole Stay Touch Voltage Using Earth Mat



Notes:

- a) LV neutral connected to major substation earthing system
- b) Auxiliary transformer HV metalwork earthed via earth mesh/grid

Figure 8 PNB Supply Via Dedicated Auxiliary Transformer Located Inside Earth Mesh/Grid



Notes:

- a) LV neutral connected to major substation earthing system
- b) Auxiliary transformer HV metalwork earthed via earth mesh/grid using PVC/PVC insulated conductor

Figure 9a PNB Supply Via Dedicated Pole-mounted Auxiliary Transformer Located Outside Earth Mesh/Grid

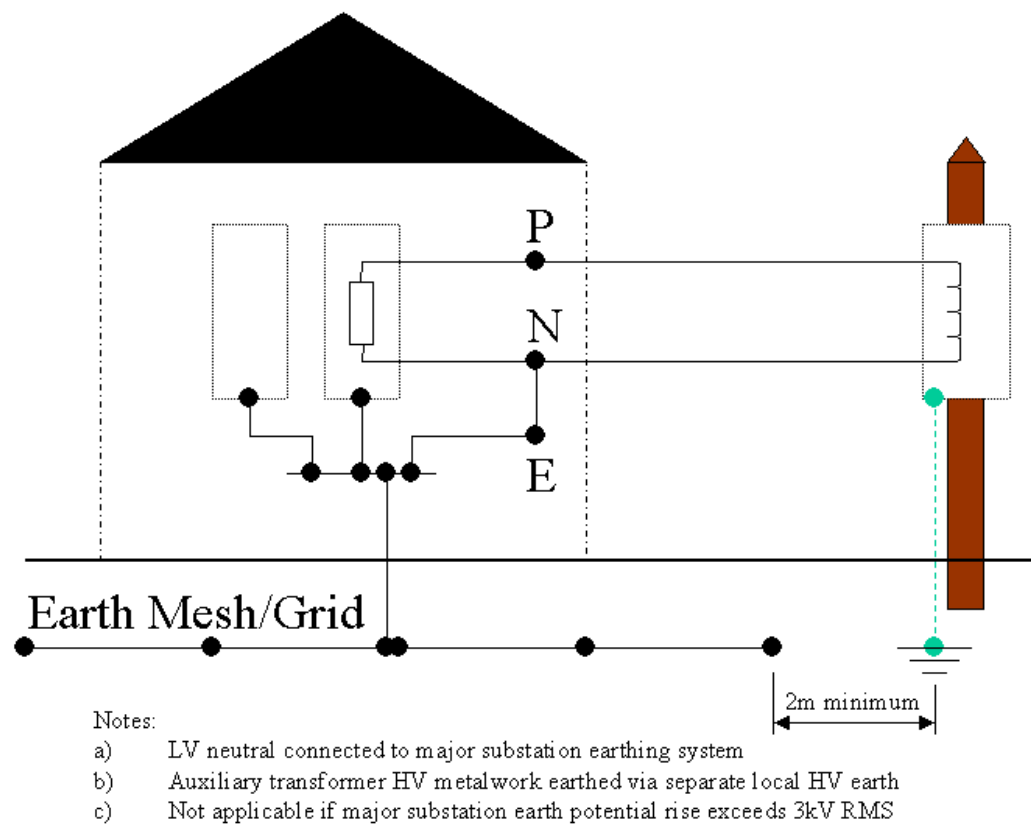
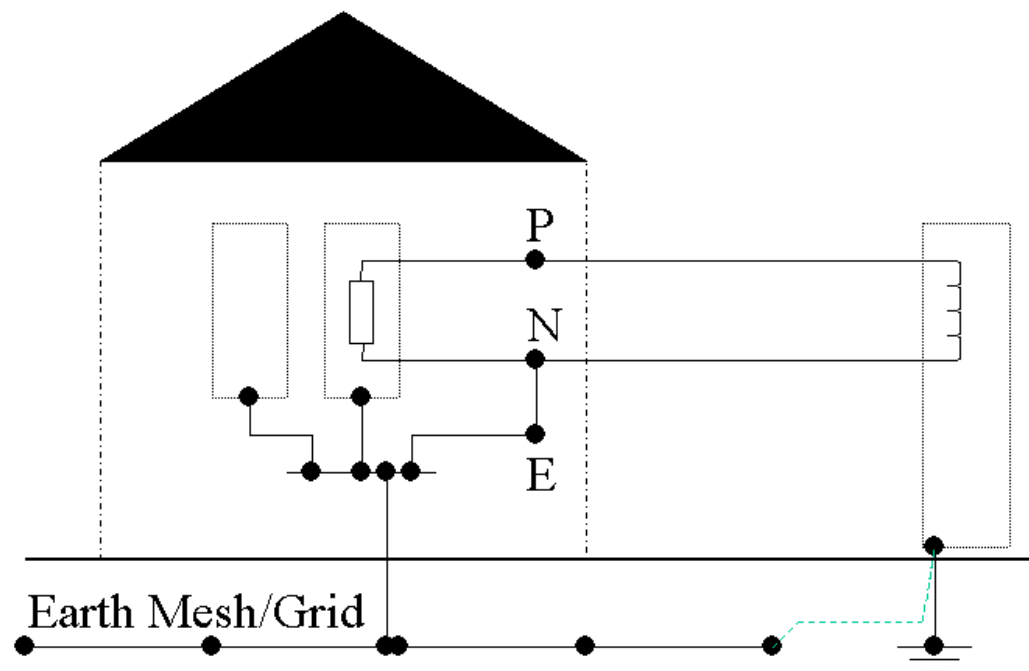


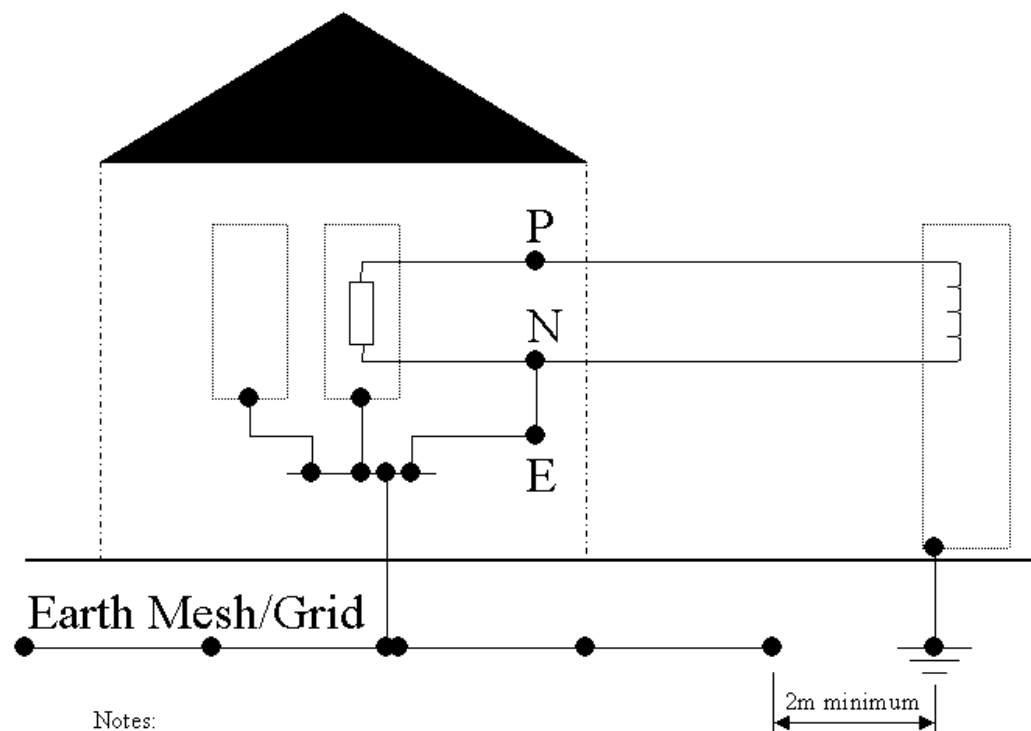
Figure 9b PNB Supply Via Dedicated Pole-mounted Auxiliary Transformer Located Outside Earth Mesh/Grid



Notes:

- LV neutral connected to major substation earthing system
- Auxiliary transformer HV metalwork earthed via earth mesh/grid using PVC/PVC insulated conductor
- Not applicable if major substation earth potential rise exceeds 3kV RMS
- Potential grading electrode may be required around the ground-mounted transformer to control touch voltage

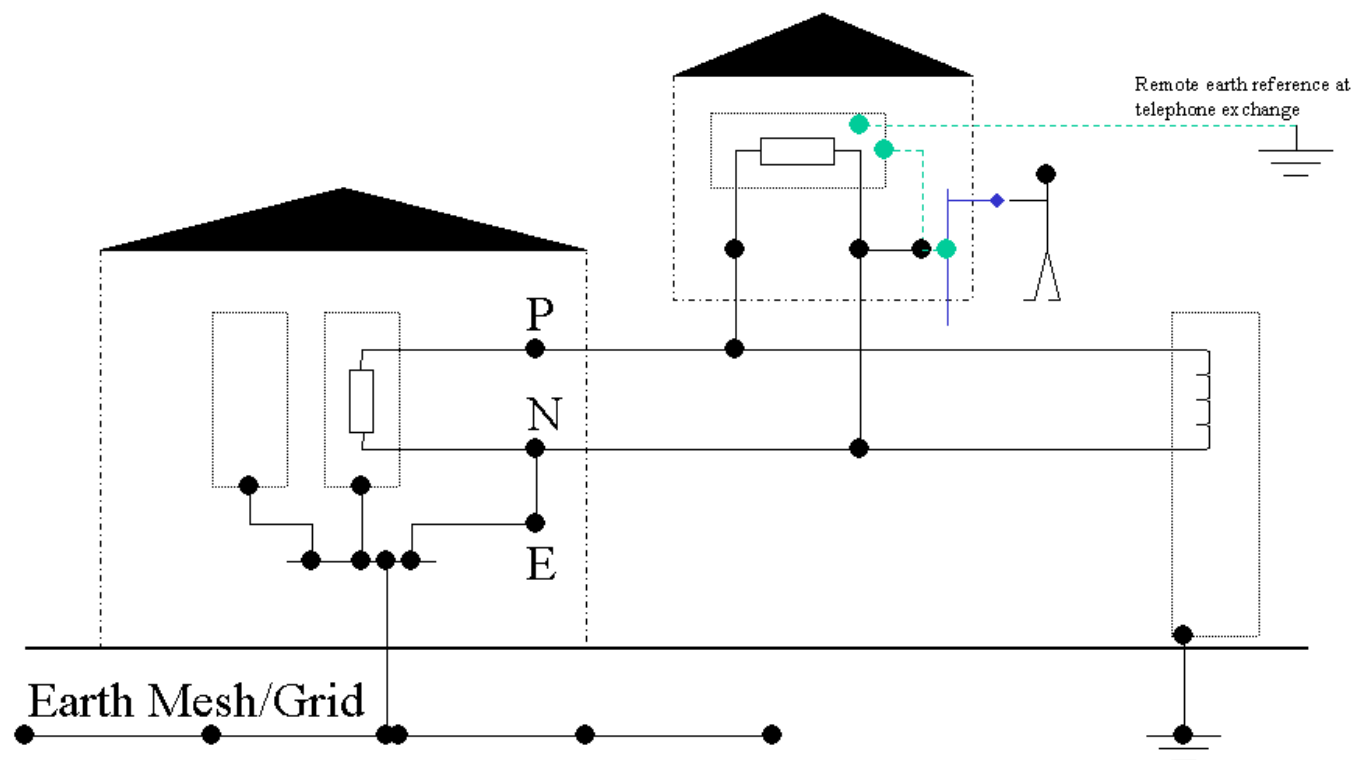
Figure 10a PNB Supply Via Dedicated Ground-mounted Auxiliary Transformer Located Outside Earth Mesh/Grid



Notes:

- a) LV neutral connected to major substation earthing system
- b) Auxiliary transformer HV metalwork earthed via separate local HV earth
- c) Not applicable if major substation earth potential rise exceeds 3kV RMS

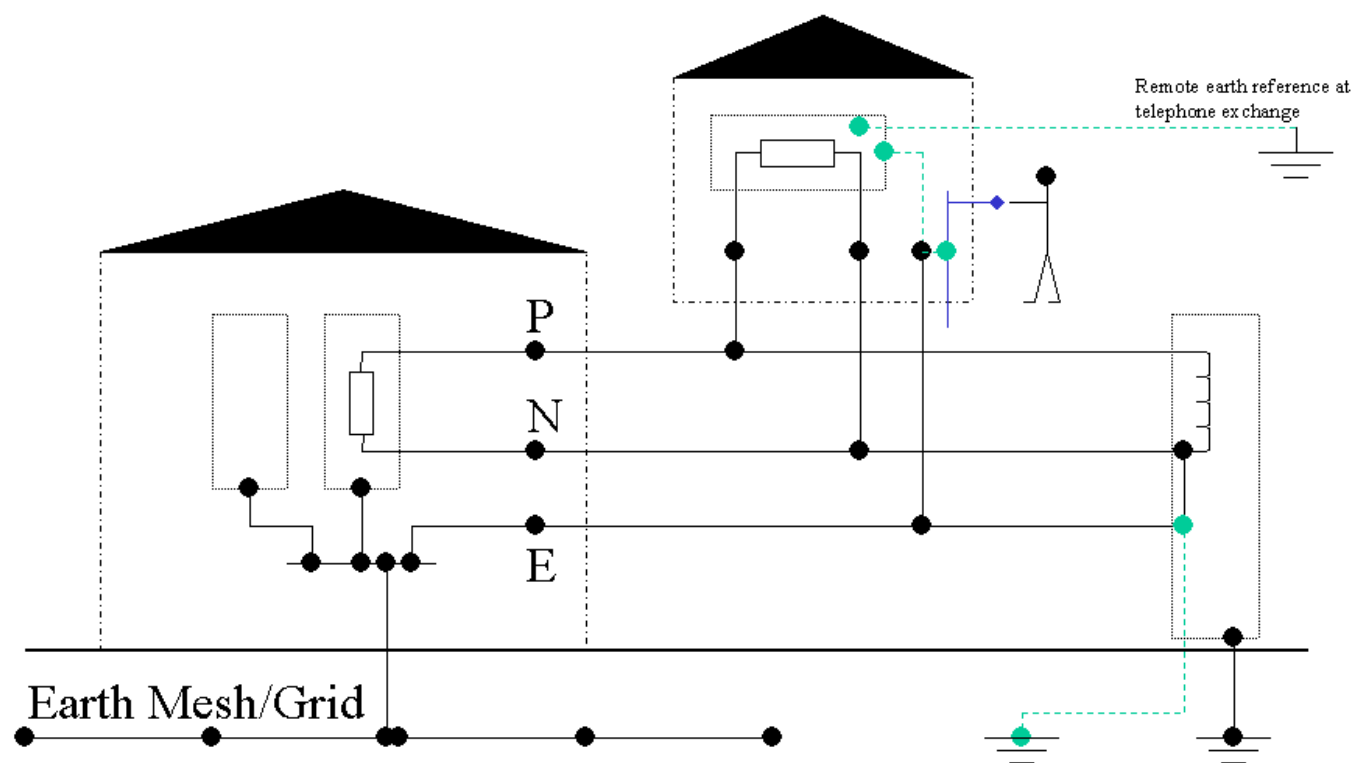
Figure 10b PNB Supply Via Dedicated Ground-mounted Auxiliary Transformer Located Outside Earth Mesh/Grid



Notes:

- a) LV neutral connected to major substation earthing system
- b) Not permitted if major substation earth potential rise $> 430\text{V}$ or appropriate touch voltage limit

Figure 11 PME Supply Via Local LV Network



Notes:

- a) LV earth connected to major substation earthing system
- b) Not permitted if major substation earth potential rise $> 430\text{V}$ or appropriate touch voltage limit

Figure 12 TN-S Supply Via Local LV Network

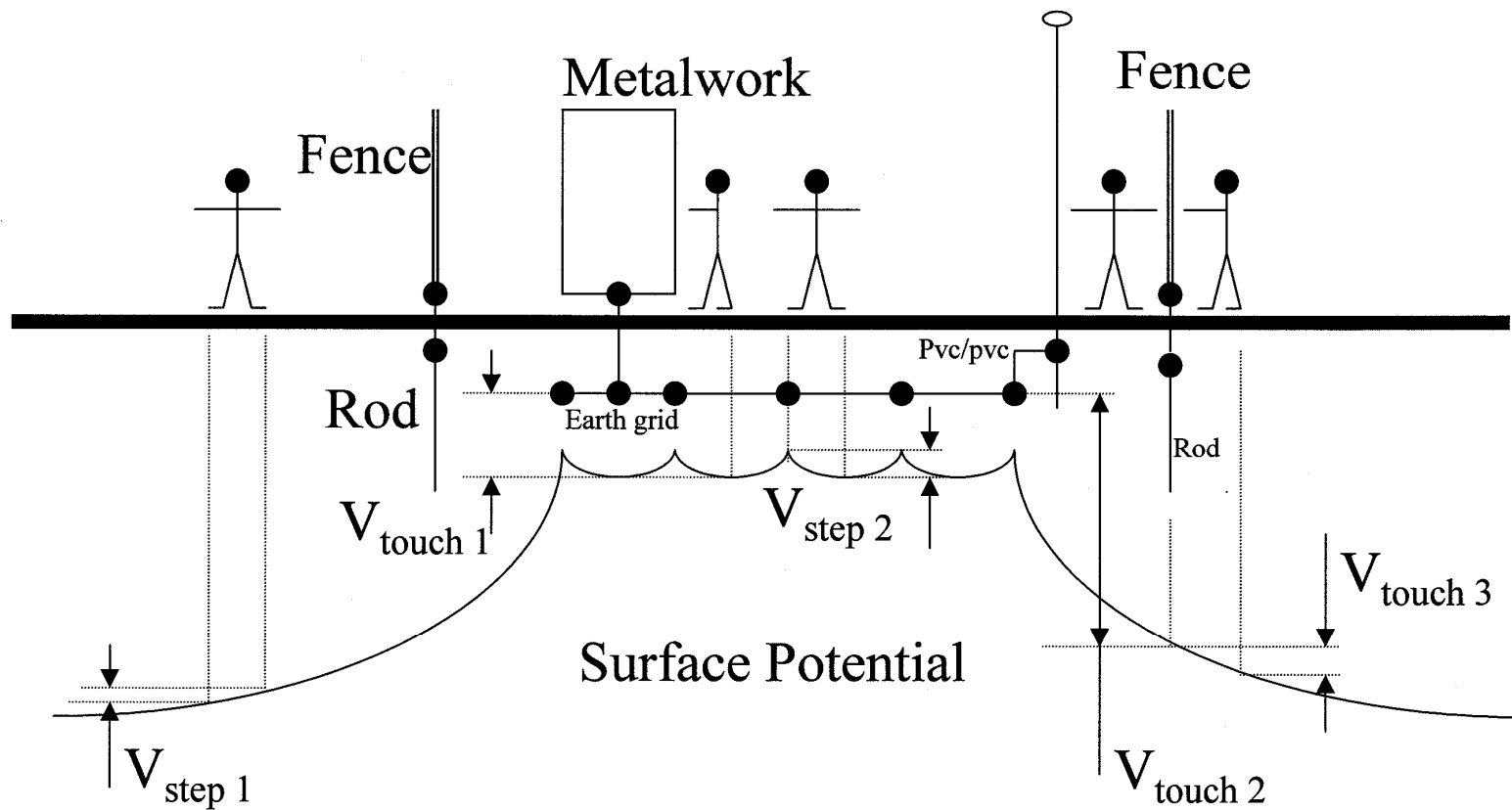


Figure 13 Local Touch and Step at Major Substation

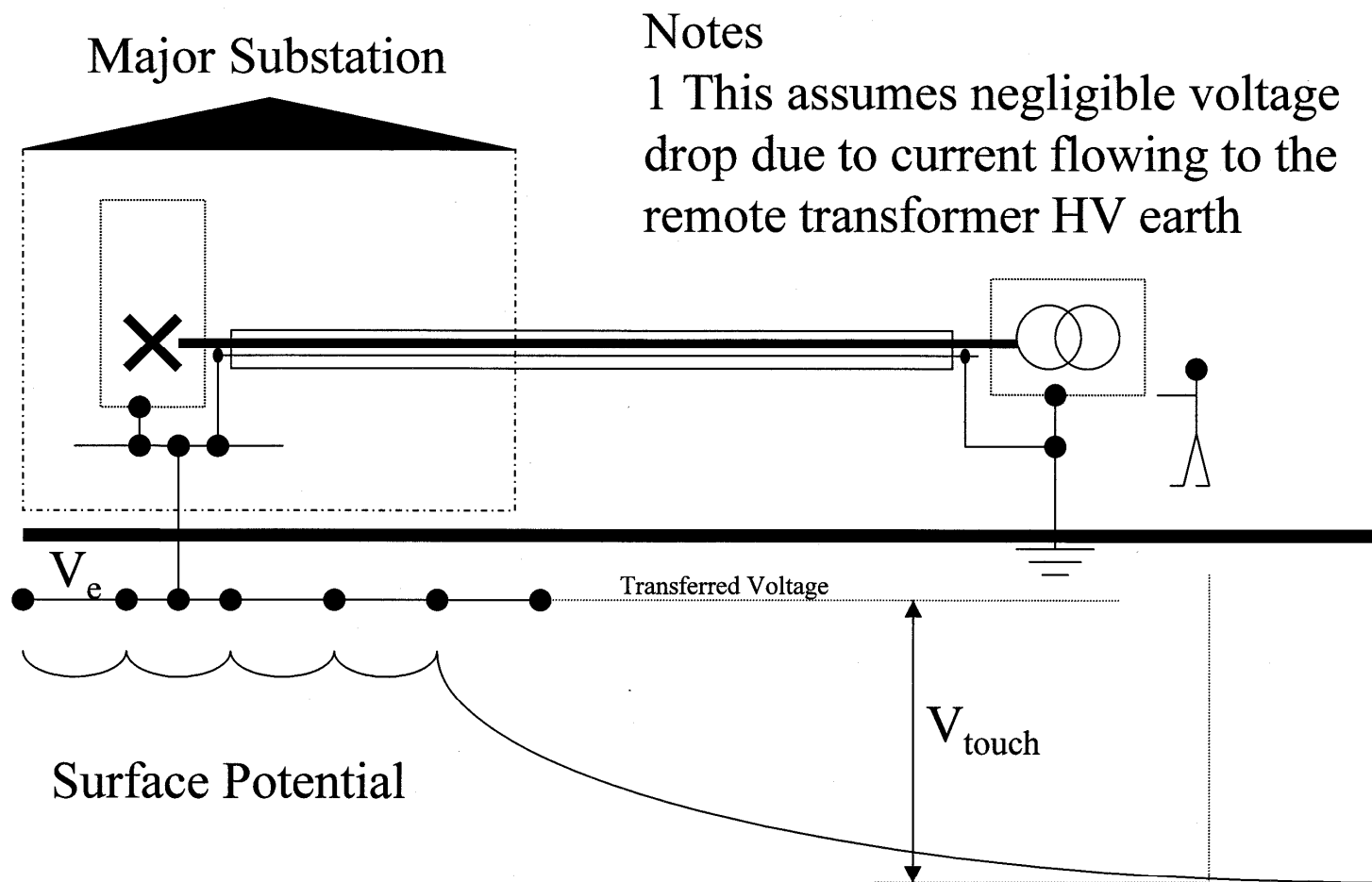


Figure 14 Transfer Of Voltage Along Insulated Sheath Cable

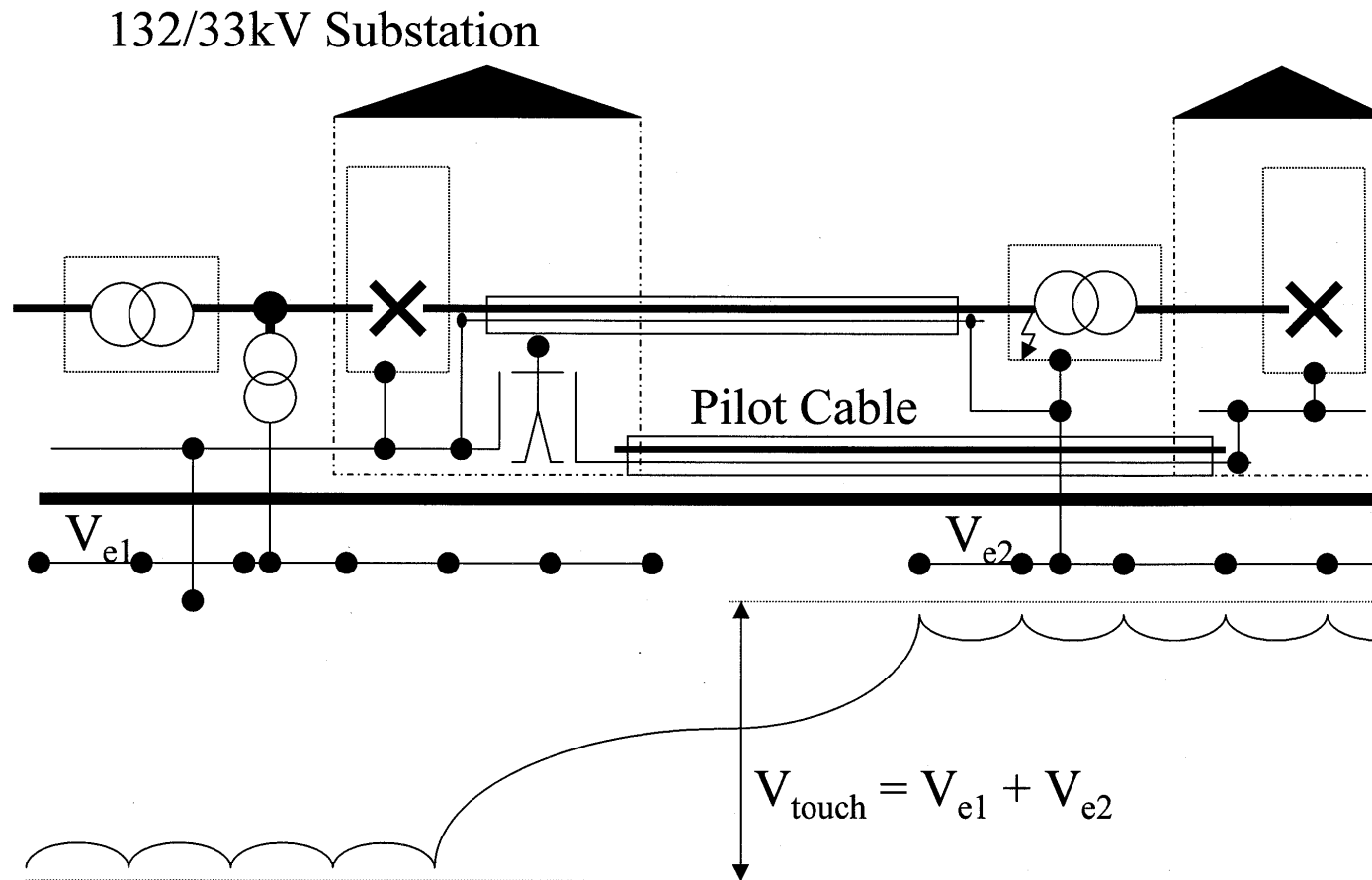


Figure 15 Transfer Of Voltage Along Single-end Earthed Insulated Cable - Fault Fed From Source Substation

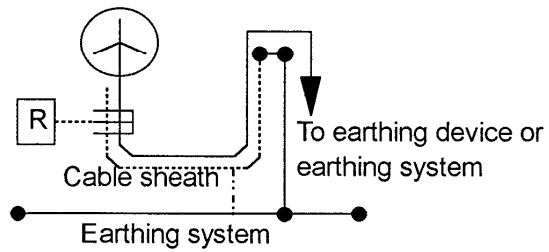


Figure 16a

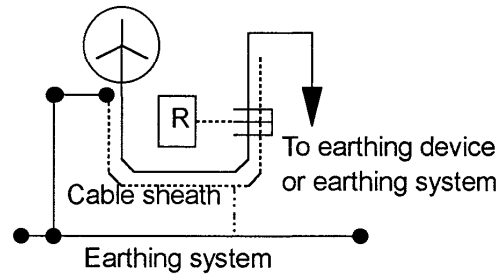


Figure 16b

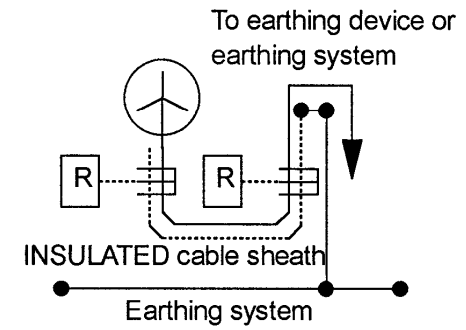


Figure 16c

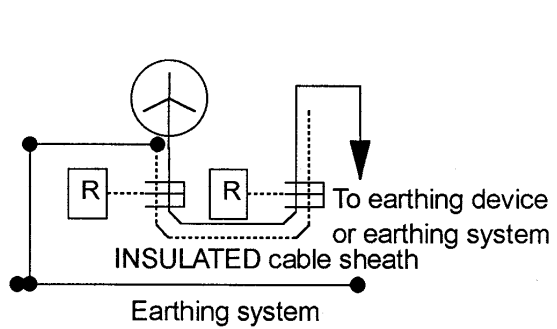


Figure 16d

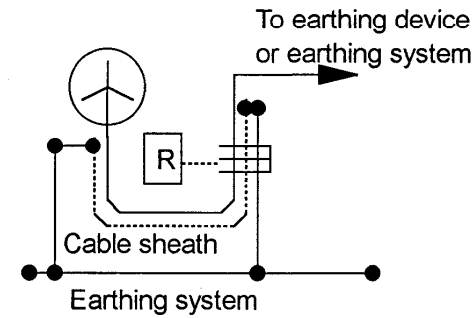


Figure 16e

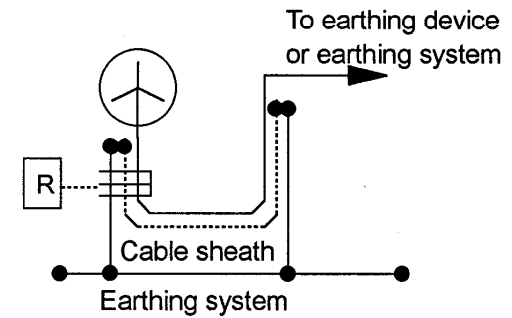
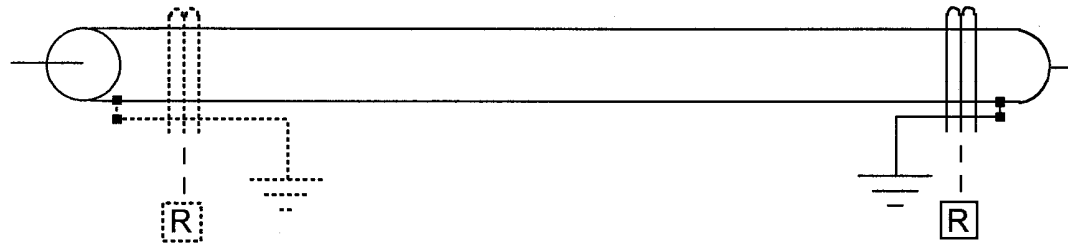


Figure 16f

Figure 16 Neutral Cable Sheath Earthing



Note: Insulated Cable Glands Provide Electrical Separation From Switchgear Metalwork

Figure 17 Power Cable Sheath Earthing

APPENDIX A

SUPERSEDED DOCUMENTATION

ST:TP21B	Design and Installation of Fixed Earthing Systems – Major Substations
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APPENDIX B

ASSOCIATED DOCUMENTATION

EE SPEC: 89/1	Fixed Earthing Systems For Major Substations
ST:TP21A/2	Fixed Earthing Systems – Voltage Limits To Prevent Electric Shock
ST:TP21K	Substation Compound Fence Earthing
ST:TP21O/2	Measurements Associated With Earthing Systems
ST:TP21S/1	Application Of Surge Arresters to Grid Transformers
ST:SP1BA/1	Standard Physical Designs For 33/11kV Substations
ST:SD3A	LVAC Supplies At Primary Substations
ENA ER S34	A Guide for Assessing the Rise of Earth Potential at Substation Sites
ENA ER S36/1	Procedure to identify and record ‘hot’ substations
ENA TS 41-24	Guidelines for the design, installation, testing and maintenance of main earthing systems in substations
BS 7430	Code of practice for earthing
BS 7354	Code of practice for design of high voltage open-terminal stations

APPENDIX C

IMPLEMENTATION

This policy shall be implemented on issue for:

- a) New installations
- b) Major modifications to existing installations
- c) Minor modifications that may cause existing installations to become non-compliant (e.g. additional lamp-posts or security posts, fence changes, noise enclosure additions etc)
- d) Off-site modifications that may cause existing installations to become non-compliant (e.g. changes to source fault levels, changes to source earthing method, significant replacement of PILCSWA cable with plastic-sheathed cable, overhead line replacement with a design that does not have an earth wire etc)
- e) If an existing earthing system is found to be unsafe.

Where any difficulty is encountered in the application of this policy, the Policy Manager shall be notified.

APPENDIX D

IMPACT

This policy is relevant to staff responsible for design, construction and management of earthing systems *and connected metalwork* (e.g. civil work). It is also relevant to staff involved with providing LV supplies at/near major substations.

APPENDIX E

KEYWORDS

Earth electrode, earth impedance, earthing, earth resistance, earthing system, earth potential rise, hot site, hot zone, LV supply, step potential, touch potential, transfer potential.