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### 3 EARTHING AND BONDING

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### 3.1 GENERAL

#### 3.1.1 Importance of Earthing

Earthing is an important integral part for the safe operation of the Transmission and Distribution System and performs several vital roles.

It is essential that the earthing and bonding arrangements for equipment associated with public electricity supply is properly designed, correctly installed, and regularly tested and maintained.

When a fault occurs, it is possible for a large current to flow in the general mass of earth. This current can cause a considerable rise in potential on earthed steelwork, which may be accessible to the public and to members of staff, particularly those who are carrying out fault switching.

Additionally, without adequate safeguards it is possible for this excessive rise in potential to be transferred onto adjacent communication cables and other power cables creating potential danger to anyone who might be in contact. This may be some distance from the actual fault.

Earthing systems are installed to provide:

- Safety of customers, the general public and UK Power Networks staff by limiting the duration and magnitude of voltage rise on steelwork and the ground surface to safe values.
- Protection for adjacent third party installations.
- A low impedance path for fault currents to enable the operation of system protection by allowing them to return to the transformer or generator neutral(s), without damage to the connected equipment.
- A means of rapidly removing overvoltages from the system.
- A reference to which all voltages can be referred and provide stability of the system.
- To maintain correct voltage levels at customers' premises.
### 3.1.2 Earthing Conductors and Resistance Values

**Table 1 – Earthing Conductors and Resistance Values**

<table>
<thead>
<tr>
<th>Network</th>
<th>Type of Earth</th>
<th>Type of Conductor</th>
<th>Size of Conductor EPN</th>
<th>Size of Conductor SPN/ LPN</th>
<th>Max Resistance Value $\Omega$</th>
</tr>
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<tbody>
<tr>
<td>LV</td>
<td>Main Neutral Earth</td>
<td>PVC covered conductor to first pin bare or covered between pins</td>
<td>35mm² copper/ 50mm² aluminium</td>
<td>70mm² copper/ 120mm² aluminium</td>
<td>&lt;20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Additional Earths</td>
<td>PVC covered conductor</td>
<td>35mm² copper/ 50mm² aluminium</td>
<td>35mm² copper/ 50mm² aluminium</td>
<td>&lt;100</td>
</tr>
<tr>
<td>11kV</td>
<td>Equipment and Surge Arrester Earthing</td>
<td>PVC covered conductor to first pin bare or covered between pins</td>
<td>35mm² copper/ 50mm³ aluminium</td>
<td>70mm² copper/ 120mm³ aluminium</td>
<td>&lt;10</td>
</tr>
<tr>
<td></td>
<td>Un-earthed Pole Bonding</td>
<td>PVC covered conductor</td>
<td>16mm² copper/ 35mm³ aluminium</td>
<td>16mm² copper/ 35mm³ aluminium</td>
<td>N/A</td>
</tr>
<tr>
<td>33kV</td>
<td>Equipment and Surge Arrester Earthing</td>
<td>PVC covered conductor to first pin bare or covered between pins</td>
<td>70mm² copper/ 120mm³ aluminium</td>
<td>70mm² copper/ 120mm³ aluminium</td>
<td>&lt;10</td>
</tr>
<tr>
<td></td>
<td>Un-earthed Pole Bonding</td>
<td>PVC covered conductor</td>
<td>16mm² copper/ 35mm³ aluminium</td>
<td>16mm² copper/ 35mm³ aluminium</td>
<td>N/A</td>
</tr>
</tbody>
</table>
3.2 HV EARTHING SYSTEM

3.2.1 HV Un-earthed Poles

3.2.1.1 General

3.2.1.2 Cross-bracing (Trussing) on H-Poles

3.2.1.3 Pole Top Stay Assemblies

3.2.2 HV Earthed Poles

3.2.2.1 General

3.2.2.2 Principles of HV Earthing

3.2.2.3 Pole Mounted Transformers

3.2.2.4 Transformer Neutral Earth

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3.2.2.6 LV Surge Arresters Fitted to Pole Transformers

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3.2.2.8 Pole Mounted Equipment Operated from Ground Level

3.2.2.9 Fitting of Operator’s Earth Mat

3.2.2.10 Cable Terminations

3.2.2.11 Surge Arresters
3.2.1 HV Un-earthed Poles

3.2.1.1 General

Please refer to Figure 1 – Pole Top Bonding and Figure 2 – Hook Stick operated ABSD to see typical arrangements.

- Some pole top equipment may be un-earthed; this is normal for crossarms and hook stick operated air-break switch disconnectors (ABSDs) or pole mounted HV fuse gear.
- The steelwork of pole mounted equipment shall be at least 5.1m (5.8m adjacent to roads) above the ground or any object within 1.5m of the pole.
- On un-earthed poles the bonding is not designed to pass fault currents. Its only purpose is to make sure that all steelwork on the pole is at the same potential to stop any leakage currents flowing, thus reducing the possibility of a pole-top fire.
- All pole steelwork supporting live equipment is to be bonded together with stranded copper conductor of at least 16mm$^2$ cross sectional area, but shall not be earthed unless it is necessary to earth other equipment on the pole. This includes stay top make-offs, pilot or tee off cross-arms, fuse gear-supporting steelwork, and hook stick operated ABSDs.
- In order to avoid high resistance connections, the conductor shall be clamped directly between steel surfaces and never ‘trapped’ between steelwork and pole.
- The direction of the run of HV Earthing shall be such that it is at least 5m from the entry point of stay rods into the ground.
- **Note:** Any screw-in pilot pins shall also be bonded to all other steelwork. This is achieved by using a Crosby clamp to attach the bond to the pin.

Figure 1 – Pole Top Bonding
Figure 2 – Hook Stick Operated ABSD

Ground Level

4.3m Minimum Old Lines
5.1m Minimum New Lines
5.6m Adjacent to Road

All Steelwork Bonded Together

Bonding Conductor

Dead End

Copper Compression compression lug

Bi-metallic compression lug

Key:
- Covered Copper Earth Conductor

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3.2.1.2 Cross-bracing (Trussing) on H-Poles
Where H-poles are fitted with cross-bracing equipment, care is to be taken that none of this can become live.

The lower member of the cross-bracing is to be greater than 3m above ground datum. For 'unearthed' constructions the cross-brace or tie-angle is to remain un-bonded and unearthed. For earthed constructions the cross bracing is to be connected to the pole-top steelwork.

Where cross bracing is lower then 3m above ground datum it shall be re-positioned to a point greater than 3m above the datum line.

3.2.1.3 Pole Top Stay Assemblies
The construction of stay assemblies are detailed in Section 5 – Pole Supports (Stays and Struts).

The pole-top make-off of all stays shall be bonded to the line supporting steelwork. This is achieved by attaching the integral king-wire in the case of preformed type of make-off, or a single wire from the stay's hand-wrapped make-off to the tie strap using the M20 x 60mm bolt and two round washers and full nut.

All stays on poles shall have an insulator fitted to prevent the bottom of the stay becoming live in the event of a pole-top insulation failure. The insulator shall be below the lowest live exposed conductor and if the stay is broken remain at least 3m above the ground.

3.2.2 HV Earthed Poles
3.2.2.1 General
This section covers the following types of construction:

- Transformers.
- Switchgear with control cubicles.
- Switchgear with operating levers at low level.
- Surge arresters and cable terminations.
- Fuses and links on earthed poles.
- Any combination of the above.

All HV earths involving hook stick operated plant, ground level switch handles and control cubicles are designed with the assumption that operators are wearing Dielectric Boots.

The barbed wire of any anti-climbing device is to be kept physically separated from the earth system.

3.2.2.2 Principles of HV Earthing
The principles of installation when earthing an HV system fall into two general principles:

- If a pole is a switching location with ground level switching handles or control cubicles:
  - The below-ground electrodes shall be installed at least 5m away and running in the opposite direction from where the operator stands.
  - Install the below-ground electrode system such that is at least 1m deep.
  - Extend the PVC covered down-lead to the start of the electrode system and install in a PVC duct (32mm alkathene service duct). The use of this ducting also ensures that the down-lead is not subjected to sharp bends which is essential where surge arresters are present.
• If a pole is not a switching location
  • HV earth shall be installed at the base of the pole.
  • If surge arresters fitted HV earth shall be 1m deep.

3.2.2.3 Pole Mounted Transformers

At pole mounted transformer sites there are two earthing systems to consider, the HV equipment earth and the LV neutral earth.

Unless there is a continuous length of HV cable directly back to the primary substation or an existing combined earthing installation exists these two earthing systems shall be electrically separated. Details of testing to confirm separation can be found in the Earthing Standards

Detailed instructions can be found in the Earthing Standards for situations where HV/LV earths may be combined.

Adequate separation between the HV equipment earth and the LV neutral earth can be achieved effectively if the LV earth electrode is installed at a separate location (minimum 8m away) from the transformer pole.

Refer to Figure 3 – Pole Mounted Transformer with Overhead HV and LV which shows the arrangements where the HV and LV mains/services are both overhead (ACD and cable guards are not illustrated).

Refer to Figure 4 – Pole Mounted Transformer with Underground LV which shows the arrangements where the LV is supplied via underground cable.

3.2.2.4 Transformer Neutral Earth

Connection to the line neutral conductor shall be with copper Cee tap connectors, bi-metallic compression connectors or IPCs in the case of ABC.

3.2.2.5 Insulation of Cable Sheaths

Where metal sheathed hessian served cable(s) is connected to a pole that supports a transformer, and separation is required between the HV and LV earth systems, the sheath of the cable shall be insulated by doing one or more of the following to ensure the HV cable and HV earth is electrically seperated from the LV cable and LV earth:

• Installing the LV electrode system outside the zone of influence (8m) of the HV cable.
• Replacing the cable (or the affected section) with modern PVC served cable.
• Installing the cable in a duct.
• Completely covering the appropriate length (8m) of the HV cable with approved insulation tape as follows:
  • Remove all loose dirt from the 8m of cable and apply two layers of approved non-hygroscopic self amalgamating tape, not less than 50mm wide, under tension at half lap.
  • Then apply overall, two layers of ‘Denso’ tape at half lap, extending 100mm beyond the ends.

3.2.2.6 LV Surge Arresters fitted to Pole Transformers

LV surge arresters are fitted between the transformer tank earth and the LV neutral, and provide a temporary connection between the two electrode systems during some fault conditions, for example when the 11kV system voltage temporarily exceeds 7.5kV with respect to true earth.

By default the base of the arrester is connected to the transformer tank and hence the HV earthing system.
Figure 3 – Pole Mounted Transformer with Overhead HV and LV

Key:
- Blue: Covered Aluminium Earth Conductor
- Green: Covered Copper Earth Conductor
- Red: Bare Earth Conductor
- Orange: Phase Conductor
- Blue: Neutral Conductor
- Black: Bare LV Overhead Line

- All Steelwork Connected to HV Earth
- HV Earth
- HV Earth Terminal
- Transformer Earth Terminal
- LV Network either ABC or Open Wire
- LV Earth
- LV Earth Electrode (to achieve max 20Ω)
- HV Earth Electrode (to achieve max 10Ω)
- Bi-metallic Splice (100mm below lowest crimp)
- Bi-metallic Splice (150-300mm above ground)
- Insulated for a Minimum of 3m Above Ground Level
- Mechanical Protection for a Minimum of 2m
- Cable Guard
- Cable Guard
- Min 8m Separation
- 2.4m min
- 1m
- 2.4m min
- 8m
- Covered Copper Earth Conductor
- Bare LV Overhead Line
Figure 4 – Pole Mounted Transformer with Overhead HV and Underground LV

Key:
- Covered Aluminium Earth Conductor
- Covered Copper Earth Conductor
- Bare Earth Conductor
- Phase Conductor
- Neutral Conductor

Ground Level

8m Separation

1m

2.4m min

LV
Earth Electrode
(to achieve max 20Ω)

2.4m min

LV CNE Cable
(PVC Covered)

Bi-metallic Splice
(150-300mm above ground)

Bi-metallic Splice
(100mm below lowest crimp)

Cable Guard

Insulated for a Minimum of 3m Above Ground Level

Mechanical Protection for a Minimum of 2m

LV Earth Electrode
(to achieve max 10Ω)

All Steelwork Connected to HV Earth

Transformer Earth Terminal

Bond to LV CNE Cable Sheath

Bi-metallic Splice
(150-300mm above ground)

LV
Earth

Neutral Conductor

Phase Conductor

Bare Earth Conductor

PVC Covered

LV CNE Cable

Covered Aluminium
Earth Conductor

Covered Copper Earth Conductor

Figure 4 – Pole Mounted Transformer with Overhead HV and Underground LV
Figure 5 – Fuses or Links on Cable Terminal Pole

Key:
- Covered Aluminium Earth Conductor
- Covered Copper Earth Conductor
- Bare Earth Conductor

All Steelwork Connected to HV Earth

Note: Anti-climbing Guards Not Shown

Fuses or Links

4.3m Minimum Old Lines
5.1m Minimum New Lines
5.8m Adjacent to Road

Bi-metallic Splice (100mm below lowest crimp)

Insulated for a Minimum of 3m Above Ground Level

Mechanical Protection for a Minimum of 2m

Bi-metallic Splice (150-300mm above ground)

PVC Duct Installed from Pole to Earth Rod

See Jointing Manual for making off pole terminations (Section 2 11kV)
Figure 6 – Hook Stick Operated ABSD on Cable Terminal Pole

Key:
- Covered Aluminium
- Earth Conductor
- Covered Copper Earth
- Conductor
- Bare Earth Conductor

- All Steelwork Connected to HV Earth
- PVC Duct Installed from Pole to Earth Rod
- 4.3m Minimum Old Lines
- 5.1m Minimum New Lines
- 5.8m Adjacent to Road
- 5m Separation
- HV Cable
- Bi-metallic Splice (100mm below lowest crimp)
- Insulated for a Minimum of 3m Above Ground Level
- Mechanical Protection for a Minimum of 2m
- Bi-metallic Splice (150-300mm above ground)
- Cable Guard
- Ground Level
- HV Earth Electrode (to achieve max 10Ω)

See Jointing Manual for making off pole terminations (Section 2 11kV)
3.2.2.7 Rod-operated Equipment (Earthed Poles)

Figure 5 – Fuses or Links on Cable Terminal Pole shows the arrangement for fuses or links on a cable terminal pole.

Figure 6 – Hook Stick Operated ABSD on Cable Terminal Pole shows the arrangement for a hook stick ABSD on a cable terminal pole.

3.2.2.8 Pole Mounted Equipment Operated from Ground Level

This section deals with the earthing requirements of pole mounted reclosers with ground level control cubicles and ABSDs with ground level operating handles.

The HV earth shall be positioned away from where persons could stand when moving to or from the pole base, or where they may stand to visually check the pole-top equipment.

These arrangements are identical for all HV (6.6kV and 11kV) and 33kV pole mounted hand operated switchgear.

**ABSDs with Ground Level Operating Handles**

For normal arrangements, refer to Figure 7 – ABSD Operated at Ground Level.

An earth mat shall be installed where the operator will stand.

Because the handle and bottom section of the operating rod are isolated from the top section by the insertion of an insulator, the earth mat IS NOT connected to the main earth, which shall be located on the opposite side of the pole or at least 150mm away. Care shall be taken that any handle securing bolts passing through the pole do not compromise this.

Where there is a transformer mounted on the same pole as the switchgear, and it is necessary to lay the LV electrode to that pole, then a minimum segregation distance of 8m shall be maintained between it and the HV electrode and earth mat.

Figure 8 illustrates the requirements for a ground mounted ABSD on a cable terminal pole.

**Plant with Ground Level Control Cubicles**

For normal arrangements, refer to Figure 9 – Pole Mounted Recloser with Low Level Steelwork.

The HV earth electrode system shall be installed at least 1m deep and the PVC covered down-lead connection to the electrode system run at the base of the pole.

An earth mat shall be installed where the operator will stand.

In this case the earth mat is connected to the main earth down-lead. This is because the recloser is connected to the low level cubicle by an umbilical cable.
Figure 7 – ABSD Operated at Ground Level

- 4.3m Minimum Old Lines
- 5.1m Minimum New Lines
- 5.8m Adjacent to Road
- All Steelwork Connected to HV Earth
- Insulated for a Minimum of 3m Above Ground Level
- Mechanical Protection for a Minimum of 2m

Key:
- Covered Aluminium Earth Conductor
- Covered Copper Earth Conductor
- Bare Earth Conductor

Additional annotations:
- Operating Rod
- Insulator
- Switch Handle
- Earth Mat
- PVC Duct Installed from Pole to Earth Rod
- HV Earth Electrode (to achieve max 10Ω)
- Plan View

Legend:
- 300mm
- 2750mm
- 5m Separation
- 2.4m mm
Figure 8 – ABSD on Cable Terminal Pole

4.3m Minimum Old Lines
5.1m Minimum New Lines
5.8m Adjacent to Road

Ground Level

Anti Climbing Guard
Operating Rod Insulator
Switch Handle

Cable Guard

300mm

Earth Mat

PVC Duct Installed from Pole to Earth Rod

5m Separation

2.4m mm

HV Earth Electrode (to achieve max 10Ω)

Plan View

See Jointing Manual for making off pole terminations (Section 2 11kV)
Figure 9 – Pole Mounted Recloser with Low Level Steelwork

Note: Control Cabinet is best placed ABOVE the ACD to achieve the best clearances.

Direction of Supply

Key:
- Covered Aluminium Earth Conductor
- Covered Copper Earth Conductor
- Bare Earth Conductor

Surge Arrester

Bi-metallic Splice (100mm below lowest crimp)

HV Earth

Insulated for a Minimum of 3m Above Ground Level

Mechanical Protection for a Minimum of 2m

Bi-metallic Splice (100mm below lowest crimp)

Control Unit

Mechanical protection from ground to base of control unit

Run control unit earth below ground.

Earth Mat

HV Earth Electrode (to achieve max 10Ω)

Plan View

Note: VT Neutral Earth Not Shown

Note: Control Cabinet is best placed ABOVE the ACD to achieve the best clearances.
3.2.2.9 Fitting of Operator’s Earth Mat

Refer to Figure 10 – Earth Mat Configurations.

When plant is operated manually at ground level, either by a switch handle or from a pole mounted cubicle, an earth mat shall be installed directly below where the operator will stand. The object is to equalise the potential between the switch handle/control cubicle and the earth mat, thus minimising the risk of shock to an operator should a failure of insulation occur on the pole.

On ABSD poles the switch mat conductors shall be separated from the other earth conductors by a minimum of 150mm.

Note: The earth mat should be installed at a maximum depth of 300mm below-ground. Where considerations need to be taken into account i.e. activities around the pole may pull up the mat if buried at 300mm or higher then only in these exceptional circumstances the mat can be buried at a maximum depth of 500mm.

Buried Copper Preformed Mat

The preformed copper mesh mat in Figure 10(a) should be used in preference to the Copper Loop (b) and is available from stores.

Prior to backfilling on to the earth mat an Earthing Compound shall be used. It has been designed to help to prevent copper earthing theft. An added benefit is that it is conductive and has been designed to enhance earthing systems, improving the earthing performance over conventional methods.

1. Dig a whole out the same size as the 1mx1m copper earthing mat.

2. Empty two bags of the Earthing Compound into the base of the whole and level out. Ensure appropriate PPE is used.

3. Place the earthing mat on top of the earthing compound. Empty another 2 bags of the compound on to the top of the mat and level off.

4. Ensure the earth wire connecting lug/bolt is not covered with the compound. This will allow for re-attachment to the buried earth mat without removing it from the ground.

5. Backfill with excavated soil.
Figure 10 – Earth Mat Configurations

(a) Preformed Surface Laid Earth Mat  
(b) Earth Mat using Bare Conductor

Buried Copper Loop

- The mat shall be connected to the switch handle/control cabinet and constructed from a continuous loop of bare 32mm² hard drawn copper conductor.
- The conductor is woven in the ground such that the conductors are not closer than 150mm or greater than 305mm apart.
- Each end of the conductor shall be connected to the two switch handle earthing bolts using compression lugs.
- The two ends of the earth mat which are connected to the operating handle/cubicle shall be protected against mechanical damage above ground with a protective cover.
- Copper pegs should be driven into the shoulder of the loops to maintain the constructed shape whilst burying the copper loop.

3.2.2.10 Cable Terminations

Where a section of 11/6.6kV cable is installed in the run of an overhead line, or teed from an overhead line, an electrode system shall be installed at each end.

The cable sheath (and armour if fitted) shall be bonded to the mounting steelwork associated with the termination. The connection between cable, steelwork and earth conductor shall be kept as short as possible and shall be direct, i.e. not via a support bolt.
3.2.2.11 Surge Arresters
Surge Arresters are installed to rapidly remove over-voltages from the system and prevent damage to plant and equipment. The main causes of such over-voltages are direct or induced lightning strikes.

In order to divert these over-voltages to earth, it is desirable to present them with as smooth a path as possible i.e. an earthing conductor with no kinks or sharp bends. For this reason the buried earth electrode system shall be at the base of the pole and kept as short as possible i.e. deep driven if practicable. However, if rod operated plant switch handles or low level cubicles are present, then this arrangement is unsuitable and the below-ground earthing shall be located at least 5m away from where an operator might stand.

Running the earthing conductor through PVC service duct helps maintain a smooth, slow bend which helps reduce its impedance to lightning surges.

Connecting Surge Arresters
The earth terminals of surge arresters shall be collectively bonded to the main earth system. On modern pole terminations this is achieved via the supporting crucifix steelwork.

The pole steelwork is connected by an individual earth connection to the main earth down-lead.

Below-Ground Earthing with Surge Arresters
Where one rod is insufficient to achieve $10\Omega$, additional electrodes shall be installed in a star formation around the initial electrode (refer to Section 3.4 – Earth Electrode Arrangements). The separation distance between electrodes shall be equal to the length of the first electrode. This reduction is because the sphere of influence of an electrode carrying high frequency current is less than those conducting power frequency faults.

Because high step potentials can arise, the top of the first earth electrode shall be a minimum of 1m below-ground level and the down-lead shall be PVC insulated to this point.

Down-lead and Connections
The down-lead from the surge arresters shall be kept as straight as possible from the surge arrester base to the earth electrode with no kinks and no sharp bends.

It shall be situated $180^\circ$ away on the pole from any other earthing (especially earth mats), PVC insulated and protected with a cable guard from 150mm below-ground level to 100mm above the anti-climbing guard.

The remainder of the pole steelwork and equipment shall be individually connected to the main earth down-lead.
3.3 LV EARTHING SYSTEM

3.3.1 LV Neutral Earthing
On LV systems the neutral conductor is connected to earth at the supplying transformer. This connection is at:

- The star point of the winding of a three-phase transformer
- The mid-point of the winding of a split-phase transformer
- One end of the LV winding of a single phase transformer

Load shall be equally balanced across phases along a feeder as far as practically possible. (This is the most effective mitigation against neutral voltage rise caused by a discontinuous neutral on radial feeders).

Good load balance will also minimise neutral voltage rise under normal operating conditions, reduce losses, and maximise the load capacity available from the assets concerned.

It is the best way to reduce risks associated with broken neutrals and is an extremely important factor in network operation and design.

On new networks, which shall normally be PME, the design shall clearly indicate the phase to which new customers are to be connected.

The diagram below shows that on a perfectly balanced system when all the phase currents are the same (with or without a neutral-earth connection) the single phase volts would be 230.

However, if the star point of an unbalanced system is not connected to earth (at or around zero volts) the phase-neutral voltages can vary considerably.
### 3.3.2 PME and PNB

The LV system is constructed so that, whenever practicable, a PME earthing terminal can be made available at every customer’s intake, providing a solid metallic return from the earth terminal of the installation back to the substation transformer neutral terminal.

There are a few exceptions where PME cannot be offered due to safety related reasons. Such installations where PME is not appropriate are caravans, boats, building sites etc.

Special conditions apply to petrol stations, swimming pools, sports facilities, quarries, horticultural and some farm buildings etc. as do public lighting and street furniture. Refer to EDS 06-0017 ‘Customer Installation Earthing Design’ for details.

#### 3.3.2.1 Protective Multiple Earthing (PME)

With PME the neutral conductor itself provides the return path from the customer’s terminal to the transformer neutral.

By earthing the combined neutral/earth conductor at multiple locations it’s potential shall be kept as close to that of true earth as possible.

At the customer’s termination, either the neutral is linked to the customer’s earthing terminal or in modern cut-outs a common neutral/earth block is fitted.

#### 3.3.2.2 Protective Neutral Bonding (PNB)

The general arrangement of PNB is that the LV neutral is earthed at one point only, usually at or close to the customer’s supply terminals. The customer’s electrical installation requirements are exactly the same as for PME. PNB is only used where a single customer is connected to a transformer.

Wherever possible, existing PNB installations shall be upgraded to PME by installing a new LV electrode system at the transformer.

#### 3.3.2.3 Application of PME

Refer to Figure 11 – Neutral Conductor Earthing Requirements for PME and ECS 06-0023 ‘Secondary Distribution Network Earthing Construction’.

An additional electrode consists of a standard earth electrode driven to a depth of 2.4m or greater (i.e. two rods). They are connected to the neutral via insulated conductors as per Section 3.1.2.

An additional earth electrode shall be installed at the end of each main. Alternatively, connecting the combined neutral/earth conductor to that of another PME main (as is common in urban areas) shall serve the same purpose.

Additional earth electrodes shall be installed to ensure that the distance between electrodes does not exceed intervals of not more than six spans along the LV route of an overhead line.

#### 3.3.2.4 Earth Fault Loop Impedance

The phase to earth loop impedance (ELI) is measured at (or close to) the cut-out terminals.

Refer to EDS 06-0004 ‘Earth Fault Loop Impedance Requirements’ for details of earth fault impedance.

### 3.3.3 Recording and Material Alteration of Earthing Systems

It is important that all earthing systems are correctly installed, recorded and meticulously maintained.

All new installations and alterations shall be reported to ART (Asset Registration Team).
Figure 11 – Neutral Conductor Earthing Requirements for PME

- **Single Customer**, no Length Restriction for Earthing
- **Secondary Substation**
- **Main Electrode Installed on the Main Line every 6 Poles**
- **Branch to Multiple Customers or Multiple Occupancy Building Requires end of Main Electrode or Alternative Neutral/Earth Connection**
- **End of Main Electrode or Link to next PME Main**
- **4 or less Customers no Additional Earth Required**

**Key:**
- Main
- Branch
- Service
- PME Customer
- Earth Electrode
3.4 EARTH ELECTRODE ARRANGEMENTS

The two traditional methods of installing an earthing system are:

- **Deep Driving:**
  Rods are driven directly down with the aid of post rammers, hydraulic/pneumatic power packs or a hydraulic breaker attachment on a mini-excavator.

- **Linear Trench:**
  Rods are driven in along a linear trench.

Other configurations that may be considered are:

- **Star Arrangement:**
  A star arrangement is a particularly effective form of an electrode system when surge arresters are deployed.

The following table shows how to determine the number of electrodes required to achieve a 10Ω resistance in different soil types. This table shall be used in conjunction with Figure 12 – Star Earthing Arrangements.

### Table 2 – Number of Electrodes for 10Ω Resistance

<table>
<thead>
<tr>
<th>Soil Type (for Reference)(1)</th>
<th>Typical Soil Resistivity (m)(2)</th>
<th>Arrangement Number (3)</th>
<th>Value of X in m (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loam</td>
<td>25 or less</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Chalk</td>
<td>50 or less</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Clay</td>
<td>100 or less</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Sand/Gravel/Clay mix</td>
<td>150 or less</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>200 or less</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>500 or less</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Slate/Shale/Rock</td>
<td>500+</td>
<td>Site specific design required</td>
<td></td>
</tr>
</tbody>
</table>

- **‘Crowsfoot’ Arrangement:**
  - Another example of an earthing configuration is the ‘Crowsfoot’
  - A typical illustration is shown in Figure 13 – Three Limb ‘Crowsfoot’ Earth

- **Herringbone arrangement:**
  - Where the area to carry out earthing is limited, another arrangement of electrodes to consider is the ‘herring bone’.
  - The minimum spacing between earth rods is the depth of the rod tip below-ground (i.e. 2400mm + 0.45mm for two rods coupled together).
Figure 12 – Star Earthing Arrangements

Note: Pin arrangements in Figure 12 refer to Table 2 column 3.
Figure 13 – Three Limb ‘Crowsfoot’ Earth on PT in Corner of Field
3.5 SITING OF EARTHING SYSTEMS

3.5.1 General

When an electrode system has to be laid for a pole mounted item of plant, unless cables are being laid to/from the pole, a new trench has to be opened. The route shall be primarily dictated by safety, practicality and wayleave issues.

Where a number of pole transformer sites are available, then the one yielding the best soil resistivity results shall be chosen.

Refer to Figure 14 – Typical Underground Earthing Arrangements and Table 3 – Below-Ground Earthing Arrangements, to assist in making a judgement as to the type and possible extent of the earthing system to be installed.

- Measure the soil resistivity and compare the values with those in column (2).
- The amount of electrode which shall provide the required resistance using deep driven conductor is shown in column (3), whilst the amount required using short rods and horizontal conductor is shown in the column (4).

Excavation practices are detailed in Section 2 – Safety Aspects, Tools and Equipment. Special consideration shall be given to determine the location of other utilities buried plant, especially telecommunications cables. In agricultural fields water pipes feeding drinking troughs should be located and avoided. Land drains may need repairing if damaged.

Examples of good routes for buried earths (electrode system) are out of the way of humans, animals and conducting material near the surface. The electrode system shall preferably be installed alongside hedges or in the pavement area.

Bare copper HV electrodes shall not be run alongside LV cables.

Where a cable is laid to the pole, the opportunity shall be taken to lay the appropriate electrode systems at the same time, but only lay HV earths alongside HV cables and LV earths alongside LV cables.

Measure and record the soil resistivity of the route (or routes if there is more than one to choose from).

3.5.2 Non-desirable Locations

The following are non-desirable areas for main earths to be installed:

- Where persons could stand whilst moving to or from the pole base, or where they may stand to visually check any pole-top equipment.
- In areas of camping or caravan parks where persons may be bare footed.
- Near metal fence posts (from which a minimum clearance of 1m is required).
- Across main farm gates, especially where these are on regularly used paths to stables or milking parlours.
- Near drinking troughs.
- Across open fields (risk to grazing animals as well as risk of damage by farm equipment etc). Refer to Figure 13 for correct installation to prevent earths going into open fields.
### Table 3 – Below-Ground Earthing Arrangements

<table>
<thead>
<tr>
<th>Soil Type (for Reference)</th>
<th>Typical Soil Resistivity ($\Omega$ m)</th>
<th>Earth Electrode Arrangement</th>
<th>20$\Omega$ Resistance</th>
<th>10$\Omega$ Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(5)</td>
<td>(6)</td>
</tr>
<tr>
<td>Deep-Driven Vertical electrodes</td>
<td>Deep-Driven Vertical electrodes</td>
<td>Short-Vertical electrodes</td>
<td>Deep-Driven Vertical electrodes</td>
<td>Short-Vertical electrodes</td>
</tr>
<tr>
<td>Loam</td>
<td>25 or less</td>
<td>1 x 4.8m rod</td>
<td>1 x 2.4m rod</td>
<td>1 x 4.8m rod</td>
</tr>
<tr>
<td>Chalk</td>
<td>50 or less</td>
<td>1 x 4.8m rod</td>
<td>2 x 2.4m rods + 3.6m conductor</td>
<td>2 x 4.8m rods + 7.2m conductor</td>
</tr>
<tr>
<td>Clay</td>
<td>100 or less</td>
<td>2 x 4.8m rods + 7.2m conductor</td>
<td>3 x 2.4m rods + 10.8m conductor</td>
<td>3 x 4.8m rods + 14.4m conductor</td>
</tr>
<tr>
<td>Sand/Gravel/Clay mix</td>
<td>150 or less</td>
<td>2 x 4.8m rods + 7.2m conductor</td>
<td>4 x 2.4m rods + 10.8m conductor</td>
<td>5 x 4.8m rods + 28.8m conductor</td>
</tr>
<tr>
<td></td>
<td>200 or less</td>
<td>3 x 4.8m rods + 14.4m conductor</td>
<td>6 x 2.4m rods + 18m conductor</td>
<td>7 x 4.8m rods + 43.2m conductor</td>
</tr>
<tr>
<td>Slate/Shale/Rock</td>
<td>500</td>
<td>Site specific design required</td>
<td>Site specific design required</td>
<td>Site specific design required</td>
</tr>
</tbody>
</table>

Column (a) denotes Each deep-driven vertical electrode comprises one 4.8m rod (4 x 1.2m rods coupled together). The top of each deep-driven electrode shall be at a minimum depth of 0.6m below ground level. Further electrodes (if required) are spaced 7.2m apart.

Column (b) denotes Each short-vertical electrode comprises two 1.2m rods connected together buried at a minimum depth of 0.6m below ground level. Further electrodes (if required) are spaced 3.6m apart connected together using bare copper conductor.
3.6 INSTALLING AN EARTHING SYSTEM

3.6.1 Earth Rods and Electrodes
Refer to Figure 16, Copper Clad Earth Rod and Fittings.
They are installed by attaching a coupler to the top of one rod and screwing in a driving head (Note: the driving head is reusable). The rod is then driven into the ground:

- Manually using a sledge hammer or post rammer.
- Mechanically using hydraulic or pneumatic power packs.

Once the top of the rod is just above ground level the driving tip is removed and a second rod screwed on using a coupler. It is important that the two rods are tightly joined, providing a good electrical connection.

The process can then be repeated if deep driving techniques are being employed.

3.6.2 Adding Earth Electrodes
If a single deep driven electrode is not being installed, additional electrodes (double length rods) shall be installed in the trench to bring the earth resistance down to the required value.

With the exception of surge arrester earthing, the maximum horizontal spacing of additional electrodes is 1.5 times the depth below-ground level of the tip of the electrodes. For practical purposes this is normally simplified to 1.5 times the length of the earth rod, i.e. 2.4m electrodes are spaced 3.6m apart.

For surge arrester earthing additional earth rods are spaced at 1 x length of the earth rod, i.e. 2.4m electrodes are spaced 2.4m apart.

3.6.3 Joining Earth Electrodes
The connection to the first earth electrode and to any subsequent additional electrodes via connecting conductor is preferably to be made by using a Compression Cee Tap, or can alternatively be made by use of a Copper/Bronze Mechanical Connector.

In all cases, the surface of the earth rod at the connecting position and the earthing conductor shall be degreased and well abraded with emery cloth or a scratch brush to remove any oxidation.
3.6.4 Running Main Earth Down-lead

The main earthing down-lead runs from the top of the pole and is connected to the underground electrode system.

The down-leads shall be as straight as possible. The use of a come-a-long clamp and a small pull-lift attached to a temporary coach bolt fitted below-ground level on the pole can help to achieve this.

The down-leads shall not contain kinks or sharp bends. Where bends are necessary, they shall be as gradual and smooth as possible.

Cleat the insulated earth conductor to the pole below the cable guard at intervals of about 0.5m.

Figure 15 – Copper Clad Earth Rod and Fittings
3.6.5 **Connections to Down-lead**

On earthed poles, individual items of pole mounted equipment and steelwork are individually connected to the main HV earthing conductor using Ceetaps and short lengths of copper conductor with appropriate size lugs.

**Note:** This connection is made with the same size and type of conductor used for the main earth.

It is not bonding conductor as it has to be able to pass fault current.

Connections to the down-lead shall be made individually in a sequential order from the top of the pole to the bottom. Such an arrangement aids staff in visually confirming the integrity of the earthing system before ascending the pole.

3.6.6 **Protection of Earthing Conductors**

To prevent harmful step potentials on the ground surface, the conductor shall be PVC insulated to a minimum distance of 500mm below-ground level.

The conductor shall be similarly insulated above ground and covered with a protective cable guard from 150mm below-ground level to 100mm above the anti-climbing guard.

3.6.7 **Excavation, Testing and Reinstatement of Earthing Systems**

1. Drive the main (first) electrode straight down into the earth at the required position.

2. Test the resistance to earth as described in Section 3.8 – Earthing Electrode and Soil Resistivity Testing. If the measured resistance is too high, excavate to the position of the next electrode and connect the electrodes together.

   The spacing between earth rods is shown in 3.2.1.2.

3. Repeat (b) until the required resistance value is attained.

4. On completion backfill and permanently reinstate the excavation.
### 3.7 OTHER SITUATIONS

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<th>Section</th>
<th>Description</th>
<th>Page</th>
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</thead>
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<td>3.7.2</td>
<td>Cellular Radio Transmitters Situated on National Grid Towers</td>
<td>29</td>
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<td>3.7.6</td>
<td>Guard Wires – Power Line Crossings</td>
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</tr>
</tbody>
</table>

#### 3.7.1 Lines Supplying Equipment Mounted on Transmission Towers
Instructions shall be supplied in each individual case.

#### 3.7.2 Cellular Radio Transmitters Situated on National Grid Towers
Instructions shall be supplied in each individual case.

#### 3.7.3 Third Party Equipment (BT etc) on Shared HV or EHV Poles
This section deals with telecommunications equipment (usually BT) attached to HV poles under licence. The purpose of this bonding is to protect operatives working on shared HV or EHV poles from current leakage. No 3rd party equipment of any sort is permitted to be attached to HV or EHV without a licence being granted by UK Power Networks. It is highly unlikely that any further licences shall be granted.

The 11kV steelwork (and any HV stays) shall be connected to an earth electrode of sufficient rods to give an earth reading of less than 10Ω.

#### 3.7.4 LV Steelwork and Plant
Pole mounted equipment such as the metallic tanks of LV voltage regulators, static balancers, LV metal-clad fusegear, LV cable boxes and CNE cable sheaths shall all be bonded to the to the neutral earth conductor. However reel insulator supports, pole bolts, D-irons, pole-top stay make-offs and heat shrink cable terminations mounted at line conductor height, all on LV wood poles do not require bonding together.

If the LV line has metallic steel supports then the steel pole shall be bonded to the LV neutral at each pole location. This ensures a pole does not remain ‘live’ in the event of a phase fault on the pole.
3.7.5 HV and LV ABC Combined Construction
An LV overhead line is erected below an HV overhead line on the same pole.

Typically modern construction of this type of overhead line shall consist of HV Covered Conductor and LV ABC although existing configurations of PVC covered HV and LV conductors are still in use.

On poles without plant or cables on them, the 11kV steelwork (and any HV stays) shall be connected to an earth electrode of not less than two 1.2m rods coupled together to form one 2.4m electrode. This shall give a reading of around 50Ω.

The LV fittings shall not be earthed; nor shall any LV stays.

HV and LV PME earths shall be separated down the pole and by 8m below-ground.

HV and LV PME earths on the same pole shall be kept 180° apart.

3.7.6 Guard Wires – Power Line Crossings
Where open LV overhead lines cross under HV overhead lines, in addition to complying with the vertical line/line crossing clearances one of the following alternative precautions shall also be employed:

- The LV line shall be replaced with ABC.
- An over-running earthwire shall be erected above the LV conductors.
- The HV conductors shall have a 1.6mm PVC radial thickness covering.

The over-running earth wire shall be 50mm² HD aluminium regardless of the type and size of the main conductors.

The earth wire shall be installed using brackets positioned on the pole to provide adequate vertical clearance, preferably with the same vertical spacing as the line conductors.

The over-running earth wire shall be treated as an HV equipment earth with separate electrodes provided at each end. Earth resistance values of the electrodes placed at each end of the crossing span shall be not more than 10Ω.

Where there are other earths associated with the LV line e.g. PME, the electrodes for the over-running earth wire shall be separated from the other earths by a minimum of 8m.
3.8 EARTH ELECTRODE AND SOIL RESISTIVITY TESTING

3.8.1 Earth Electrode Testing
Newly installed or existing earthing systems shall be measured to determine their resistance values. Details of testing can be found in Section 10 – Maintenance Tasks.

3.8.2 Soil Resistivity Testing
Ideally soil resistivity tests shall be carried out where underground earthing systems are to be installed. The results may determine to possible best direction of excavation and provide an estimate of the amount/type of earthing to be employed.

There are two methods that may be employed:

- **One Rod Method** – this is a quick and simple method which is usually sufficient for pole transformer and distribution substation earthing design.
- **Wenner Method** – this uses a four terminal earth tester to take a series of measurements at different probe spacings. These results provide an indication of the earth resistivity at different depths. This method is essential for large substation earthing design. It is also useful where the ground type varies with depth as it enables the choice to be made between shallow or deep earthing.

**One Rod Method**
A 300mm deep hole is excavated and an earth rod is driven in. A note is made of the length of rod in contact with the soil.

The earth resistance of this rod is then measured using an earth tester. (see Craft Manual Section 10 – Maintenance Tasks).

If possible, five tests should be carried out with the rod driven in at 1.2m, 2.4m, 3.6m, 4.8m and 6.0m. However, something the type of ground prencets deep rods from being driven in. This in itself is useful to find out when planning the earth system.

The measured resistance R is then multiplied by a factor from the following list:

<table>
<thead>
<tr>
<th>Depth of rod</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2m</td>
<td>1.40</td>
</tr>
<tr>
<td>2.4m</td>
<td>2.47</td>
</tr>
<tr>
<td>3.6m</td>
<td>3.48</td>
</tr>
<tr>
<td>4.8m</td>
<td>4.43</td>
</tr>
<tr>
<td>6.0m</td>
<td>5.37</td>
</tr>
</tbody>
</table>

Example: 2.4m earth rod – reading of 100 ohms. Resistivity = 100 x 2.47 = 247 ohm metres.
**Wenner Method**

A four-terminal earth tester is required, equipped with four short test probes and connecting leads. The insulation of the current lead is especially important, as relatively small leakage currents may result in large errors.

The four probes are inserted onto the ground a distance ‘A’ apart and the tester is connected as shown. The probes should not be pushed too deep into the ground as this will upset the results. The probe depth ‘B’ should be less than 20% of ‘A’.

A resistance measurement ‘R’ is taken and recorded.

The probes are then moved further apart and the sequence repeated.

The following distances of A are required to be tested: 1m, 2, 3m, 5m, 10m, 15m, 20m

The resistivity is calculated from the formula

\[ \rho = 2 \pi A R \]

e.g.

Probe spacing of A = 5m,
Resistance of R = 7.0 ohms

Soil Resistivity \[ \rho = 2 \times 3.142 \times 5 \times 7.0 = 219.9 \text{ ohm-metres} \]

It is useful to record the results in a table:

<table>
<thead>
<tr>
<th>Probe Spacing ‘A’ metres</th>
<th>Probe depth ‘B’ mm</th>
<th>Resistance reading ‘R’ ohms</th>
<th>Calculated Resistivity Ohm-metres [ = 2 \times 3.142 \times A \times R ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>15</td>
<td></td>
<td></td>
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<tr>
<td>15</td>
<td>15</td>
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<td></td>
</tr>
<tr>
<td>20</td>
<td>20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The results indicate the soils resistivity down to a depth equal to the spacing of the probes.

e.g. the resistivity for the 20m probe spacing is the resistivity down to 20m deep.

**Using the Resistivity Results**

Where the results are very similar they can be averaged out and used to predict the number or earth rods required to obtain a particular earth resistance by referring to Table 3 in Section 3.5.

Often the resistivity will vary at different depths:

- Higher near the surface and lower at depth indicate that a small number of deep earth rods will be the best option.
- Low near the surface and higher at depth indicates that a longer earthing trench with short rods will be best.
Figure 16 – Soil Resistivity Test