EARTHING AND BONDING AT SECONDARY SUBSTATIONS

1 SCOPE

This section of the Distribution Construction Manual lays down the standard for earthing and bonding of plant and apparatus at secondary substations to comply with Regulations.

2 GENERAL

Earth is defined as the general mass of earth.

Earthed means connected to the general mass of earth in such a manner as shall ensure at all times, an immediate discharge of the electrical energy without danger.

An **Earth Electrode** comprises a metal rod or system of rods or other conducting objects, such as copper tape, providing an effective connection with the general mass of earth.

Earth Electrode Systems

At every secondary substation two earth electrode systems are necessary i.e. Equipment Earthing (HV Earth) and System Neutral Earthing (LV Earth). The two systems shall be installed with suitable segregation and can only be connected together when the combined value of the systems in less than 1 ohm.

Equipment Earthing and Bonding of all the metalwork associated with the electrical equipment (other than parts which are normally current carrying) ensures effective operation of the HV fuse or switchgear controlling the circuit, where the potential of such metalwork, with respect to the general mass of earth or other adjacent metalwork could rise to a value which could cause danger to life or risk of fire.

System Neutral Earthing is necessary to preserve security of systems, to ensure that the voltage on each live conductor is restricted to such a value with respect to the potential of the general mass of earth as is consistent with the insulation level of the system.

3 HV STEELWORK EARTH

3.1 The HV steelwork in the substation shall be connected with earth by bonding an un-insulated copper conductor (in accordance with Table 1) from the earth terminal on the transformer tank or switchgear to an earth electrode system, Reference Section 6, with an ohmic resistance value as low as economically practicable, and of such a value that when contact is made between a line conductor and earthed metalwork, the resulting leakage current shall be not less than twice the current required to operate the device which will make the line dead. The earth electrode system resistance value, measured independently shall not exceed 40 ohms. The sheaths of any metallic sheathed cables shall subsequently be bonded to that established system.

3.2 The routing and position of the earth electrode system should be such as to form an equi-potential mat beneath the operating position of any of the apparatus so that the operator is protected, so far as reasonably possible, from any voltage gradient arising from an HV fault.

3.3 Where secondary substations are surrounded by metallic structures e.g. palisade fencing, all separate sections of the surround shall be bonded to the HV earth electrode system. Care should be taken to keep the earth electrode and their bonding leads as far as possible from nearby non-related metal fences, metal buildings etc., so as to avoid these becoming charged during a fault on the HV system. A distance of 3 metres is recommended if this is possible.

4 LV NEUTRAL EARTH

4.1 The LV neutral shall be connected to an earth electrode system separate from the HV earth electrode system, reference Section 6, by running a PVC insulated cable (in accordance with Table 1), from the neutral busbar in the LV pillar or fuse cabinet to an earth electrode system. The resistance of the LV neutral earth electrode system at the substation measured independently shall not exceed 40 ohms. The combined resistance of all the LV neutral electrodes, including any contribution from any metallic sheathed cables, shall not exceed 20 ohms.

4.2 Care shall be exercised to place the neutral earth electrode system outside the influence of the HV steelwork earthing system. A distance of not less than 3 metres is recommended from the nearest steelwork earth electrode or earth mat but this distance may require to be increased in cases of abnormally high resistances.

5 COMBINED HV STEELWORK AND LV NEUTRAL EARTHS

5.1 Where the earth resistance of the combined earths (HV steelwork + neutral earth + connections with earth associated with the cables connected to the substations via their sheaths) is 1 ohm or less, then the separate HV and LV earth electrode systems shall be bonded together. This is the preferred state and when this condition prevails the link provided in the LV pillar between the neutral earth bar and the pillar shell shall be closed.

5.2 Where it is not technically and economically justified to reduce the combined earth resistance value to 1 ohm or less, the HV steelwork earth electrode system shall remain segregated from the neutral earth electrode system. In this condition, where a link is provided between the neutral earth and the LV metalwork, it shall be left in the open position. A notice shall be installed in a conspicuous position within the pillar showing that this condition prevails.

6 EARTH ELECTRODE SYSTEMS

6.1 Earth electrode systems shall normally be comprised of conductors as detailed in Table 1 and earth rods complying with EA Technical Specification 43-94 Issue 3 and ScottishPower Procurement Specification No. 4389/10,000 which includes non extensible galvanised steel tubes 20 mm dia., non extensible copper clad 9 mm dia. rods and extensible copper clad 15 mm dia. rods. The rods shall be driven into the ground vertically until their tops are at least 600 mm below the surface. This depth is necessary to prevent appreciable voltage gradient on the surface of the ground in the vicinity of the electrode. The HV earth electrode system can be installed within the substation and shall cross the area on which an operator will be required to stand while operating the switchgear. The LV earth electrode system can be installed along an LV cable trench but shall not make contact with a cable or come within 3m of an HV cable. Paper insulated metallic sheath, jute or hessian served cables laid direct in the ground shall not be used as the main HV steelwork or LV neutral earth electrode system but shall be bonded to the relative systems.

6.2 Where more than one rod is necessary, then a number of rods may be installed at a distance of approximately, but not less than, 3 metres from each other. The resistance of N rods at 3 metre spacing, connected in parallel, is approximately 1.5 x R/N where R is the resistance in ohms of one rod. The connections between earth rods, where more than one are installed shall always be made using copper conductor in accordance with Table 1. The connections from the neutral/earth bar to the neutral earth electrode system shall be insulated until they are outwith the sphere of influence of HV steelwork earth system (not less than 3 metres separation).

6.3 All connections between the earth rods and the earth leads must be carefully made up, using approved clamps, adequately protected by wrapping with denso or other approved tape or cast in bitumen compound. Where connections are made using lugs and bolts then two bolt fixings shall be used.

6.4 Means must be provided for disconnecting the earth electrode system at substations for testing, and this can normally be achieved by having a bolted connection where the earth electrode system is connected on to the equipment or neutral busbar which can be undone and the lead disconnected. These disconnections must always be at copper to copper or copper to brass joints. Aluminium joints shall not be disconnected for testing.

6.5 In areas of high soil resistivity, low electrode resistances are difficult to achieve and dangerous potential gradients could occur over and around the site unless adequate steps are taken to prevent this. These potential gradients may also be imposed on the entire LV distribution system. Increasing the number of electrodes will reduce the overall earth resistance value but may result in extending the earth system outwith the confines of the substation and produce potential gradients between nearby metallic objects, e.g. metal framed buildings or fences. A lower resistance value may often be achieved by driving extensible earth electrodes deep into the ground without extending the earth system outside the substation. In rocky soil, copper tape in accordance with Table 1 may be installed.

6.6 Great care should be exercised when installing the earth electrode system particularly when hammering rods into the ground, to avoid accidents due to piercing cables or other utilities services already laid in the ground, e.g. gas, water, telephone, sewage, etc. Before commencing installation of electrodes an up-to-date plan of the site should be prepared showing the exact position of all cables and other services including cables recently laid in conjunction with the project under construction and the cables in question should be positively located, if necessary by excavating trial holes, before driving the earth rods. So far as possible, persons should avoid direct contact with earth rods being driven into the ground by using an insulated tool to steady the rod or by the use of rubber gloves.

7 BONDING

7.1 The size and type of bonding conductors to be used are set down in Table 1.

7.2 All steelwork within touching distance (2 metres) shall be bonded together, so that no potential difference can arise between units. This includes the transformer, HV switchgear, HV cables, LV feeder pillar shells, fences, exposed total enclosure metalwork and any other apparatus installed.

The bond shall be made using conductors shown in Table 1. Where theft of copper is likely, aluminium conductors are recommended for above ground with terminations similar to those in Section 4.3.3 Appendix 2 of this manual.

8 SUBSTATION EARTH POTENTIAL RISE (HOT EARTHS)

8.1 Under system earth fault conditions the neutral or earth potential near a substation rises above the true earth potential and can adversely affect telecommunications equipment in that zone. Engineering Recommendation ER G60 recommends that where the rise of potential exceeds 430 volts at Distribution substations, the substation is deemed "HOT" and additional protection is required for telecommunications equipment in the vicinity of the substation.

8.2 For all new substations, or when requested to do so, it is incumbent upon ScottishPower to calculate the 430 volt contour radius using Engineering Recommendation S34, "A Guide for Assessing the Rise of Earth Potential at Substation Sites" and advise BT or other companies involved. Additional precautions for telecommunications equipment will only be needed in the calculated "HOT" zone. This will normally be done at the design stage, reference Section 13.8 of the Distribution Design Manual, but must be confirmed at the construction stage.

9 LV SYSTEM EARTHING

9.1 At network pillars and link boxes remote from substations or at other disconnecting points on the LV system, the cable neutral and earth shall be securely bonded together using 35 mm^2 or 70 mm^2 conductor depending on the cable size. The framework of the pillar shall be bonded to the cable neutral/earth and shall be connected with a 35 mm^2 conductor to an earth electrode.

10 INSTALLATION EARTHING

The earthing of installations shall comply with the Code of Practice "Earthing of LV Distribution Networks". Where a new installation is being connected to a separate neutral and earth (SNE) network, preference should be given to adopting protective multiple earthing (PME). In certain circumstances, however, it may be technically and economically justified to extend the existing SNE earthing system.

11 TECHNICAL NOTES

11.1 In situations of high earth resistivity, there may be difficulty in obtaining the required earth electrode system resistance. This would cause high potential gradients to occur in and around the substation, which could be impressed on the whole of the LV distribution system supplied from the substation or on telecommunications equipment.

The earth resistance can be reduced by inserting more electrodes, until a low enough total resistance is achieved. This may, however, result in extending the earth system beyond the confines of the substation, and may produce dangerous proximities between the earth leads and external metal objects. It may be better in certain locations to use extensible deep driving earth electrodes, within or near the substation to obtain the same results. The LV neutral earth electrode system should always have an insulated lead, and be at least 3 metres separate from the HV steelwork earth electrode system or any metalwork bonded thereto. This is particularly important in high resistivity areas. Special care must be taken to ensure that all metalwork, including the fence and LV pillars, is bonded, and connected to the HV steelwork earth electrode system to avoid potential differences between items of apparatus, when within touching distance, i.e. within 2 metres proximity.

With the increased use of plastic covered cables it is essential to achieve sufficiently low earth electrode system resistance values.

The requirement for the electrode systems to dissipate fault current must be achieved by installing a minimum of five earth rods in every system even if a lesser number could achieve the required ohmic value of resistance.

11.2 **LV Neutral/HV Metalwork Earth System**

Should a potential gradient exist in the vicinity of a substation during an HV fault there is a risk of this being impressed on the LV system if the neutral and HV steelwork earths are connected together, and the earth system resistance is high. It is considered safe to join the two earth systems together when their combined resistance is 1 ohm or less. Where it is impracticable to achieve this resistance, care should be taken to ensure that the LV neutral is connected by an insulated lead to the electrode system which is well clear of the estimated potential gradient of the HV earth system. This may require a greater distance than the stipulated minimum of 3 metres.

11.3 **PVC Over Sheathed Cables**

In the past, advantage has been taken of the effectiveness of the sheaths of lead-covered hessian protected cables as an earth. It should be noted that PVC over sheathed cables do not contribute to the earth electrode system in this way.

11.4 **Substations Supplied by HV Overhead Lines Only**

Where substations are supplied from a metallic sheathed underground cable system, the major part of the earth fault current returns to the source (the primary substation) via the sheath, whereas in the case of an overhead line fed substation there is no metallic return path and all of the fault current must return via the earth electrode system and the general mass of earth. In these circumstances, it is most important to make sure that the earth electrode system and the earth leads have a low enough resistance and an adequate current-carrying capacity to dissipate the whole of the fault current.

11.5 **Metal Objects Adjacent to Substations**

Where there are metal structures or fences adjacent to a substation, potential differences may occur between them and the metal parts of the substation or the fences, which may be within touching distance. On the other hand, if such structures are bonded, or in contact with the substation steelwork, then the potential may be carried a considerable distance from the substation, e.g. along the wires of a fence with wooden posts and create a danger elsewhere. Substations must be designed and sited so as to avoid these situations.

11.6 Gates on Steel Fences or Total Enclosure Steel Doors

Where gates exist in steel fences or the doors of a total enclosure are of sheet steel, particularly if the fence or door is discontinuous, they shall be bonded on both sides of the gate or door to avoid the possibility of a potential developing across the gate or door.

TABLE 1 - EARTHING AND BONDING CONDUCTORS TO BE USED AT SECONDARY SUBSTATIONS

Type of Conductor	Bonding of S/Stn. Apparatus	HV Steelwork Earth Leads	LV Neutral Earth Leads
Solid Alum. PVC insulated cable to BS 6791: 1969 600/1000 V Grade	120 mm^2	-	-
Copper Strip to BS 1432: 1970	20 mm x 4 mm	20 mm x 4 mm	-
Alum. Strip to BS 2898: 1970 (EIE.M)	30 mm x 4 mm	-	-
Bare Copper Conductor Solid or Stranded	Not less than 70 mm^2	Not less than 70 mm^2	-
Insulated Copper Wire	Not less than 70 mm^2	-	Not less than 70 mm^2