Indian Standard
CODE OF PRACTICE FOR EARTHING

Power Installation and Maintenance Sectional Committee, ETDC 20

Chairman	*Representing*
Shri K. C. Grover	Central Public Works Department, New Delhi
Members	
Shri P. K. Bharucha	Insurance Association of India, Bombay
Shri A. C. Mody (*Alternate*)	
Shri V. S. Bhatia	Siemens Engineering & Manufacturing Co of India Ltd, Bombay
Shri H. Dudek (*Alternate*)	
Shri P. Bose	Eastern Regional Electrical Contractors' Association (India) Ltd, Calcutta
Shri M. Dey (*Alternate*)	
Shri L. W. Brazel	The Calcutta Electric Supply Corporation Ltd, Calcutta
Shri K. K. Bose (*Alternate*)	
Shri N. N. Chakrabarty	Government of West Bengal
Chief Electrical Engineer, Nothern Railway	Railway Board (Ministry of Railways)
Shri M. R. Chopra	Punjab State Electricity Board, Patiala
Shri K. R. Deo	The Tata Iron & Steel Co Ltd, Jamshedpur
Shri R. Padmanabhan (*Alternate*)	
Shri H. W. Horton	The Associated Electrical Industries (India) Private Ltd, Calcutta
Shri B. V. Raman (*Alternate*)	
Shri Inderjit Singh	Jyoti Limited, Baroda
Shri K. K. Gupta (*Alternate*)	
Shri K. C. Jerath	Engineer-in-Chief's Branch, Army Headquarters
Shri K. Matthan	The Federation of Electricity Undertakings of India, Bombay
Shri H. S. Kulkarni (*Alternate*)	
Shri P. R. Parikh	The Bombay Electric Supply and Transport Undertaking, Bombay
Shri B. H. Mhatre (*Alternate*)	
Shri T. S. Rao	In personal capacity ('*Bhavani*' *No. 23, Block III, Jayanagar, Bangalore*)

(*Continued on page* 2)

INDIAN STANDARDS INSTITUTION
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 1

(*Continued from page* 1)

Members	*Representing*
Shri I. C. Sanger	Delhi Electric Supply Undertaking, New Delhi
Shri P. S. Sawhney (*Alternate*)	
Shri K. S. Subrahmanyam	Hydro-Electric Construction Project, Bangalore
Shri A. Subramaniam	Madras State Electricity Board, Madras
Shri P. Narayanan (*Alternate*)	
Shri S. N. Vinze	Central Water & Power Commission (Power Wing)
Shri A. N. Singh (*Alternate*)	
Shri Y. S. Venkateswaran, Director (Elec tech)	Director General, ISI (*Ex-officio Member*)

Secretary

Shri R. C. Bajpai
Assistant Director (Elec tech), ISI

CONTENTS

Indian Standard
CODE OF PRACTICE FOR EARTHING

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 14 March 1966, after the draft finalized by the Power Installation and Maintenance Sectional Committee had been approved by the Electrotechnical Division Council.

0.2 The Indian Electricity Rules together with the supplementary regulations of the State Electricity Departments and Electricity Undertakings govern the electrical installation work in generating stations, substations, industrial locations, buildings, etc, in this country. To ensure safety of life and apparatus against earth faults it was felt necessary to prepare a code of practice for earthing. This code of practice is intended to serve as a consolidated guide to all those who are concerned with the design, installation, inspection and maintenance of electrical systems and apparatus.

0.3 This code is divided into three sections. Section 1 gives general requirements associated with earthing, such as earth electrodes, soil treatment and design considerations. Section 2 gives specific requirements for earthing in buildings, in industrial locations and of miscellaneous electrical apparatus while Section 3 gives specific requirements for earthing in generating stations, in substations and of overhead power lines.

0.4 The subject of earthing covers the problems relating to conduction of electricity through earth. The terms earth and earthing have been used in this code irrespective of reliance being placed on the earth itself as a low impedance return path of the fault current. As a matter of fact, the earth now rarely serves as a part of the return circuit but is being used mainly for fixing the voltage of system neutrals. The earth connection improves service continuity and avoids damage to equipment and danger to human lives.

0.5 The object of an earthing system is to provide as nearly as possible a surface under and around a station which shall be at a uniform potential and as nearly zero or absolute earth potential as possible. The purpose of this is to ensure that in general all parts of apparatus, other than live parts, shall be at earth potential, as well as to ensure that operators and attendants shall be at earth potential at all times. Also by providing such an earth surface of uniform potential under and surrounding the station, as nearly as possible, there can exist no difference of potential in a short distance big enough to shock or injure an attendant when short-circuits or other abnormal occurrences take place. The recommendations in this code are made in order that these objects may be carried out.

0.6 Earthing associated with current-carrying conductor is normally essential to the security of the system and is generally known as system earthing, while earthing of non-current carrying metal work and conductor is essential to the safety of human life, of animals and of property and is generally known as equipment earthing.

0.7 In the preparation of this standard, assistance has been taken from the following:

SAA Wiring Rules Part I. Wiring methods. Standards Association of Australia.

VDE 0100/11.58 Specification for the erection of power installation with rated voltages below 1 kV. Verband Deutscher Elektrotechniker.

VDE 0141/2.64 Regulations for earthing in ac installations with rated voltages above 1 kV. Verband Deutscher Elektrotechniker.

CW (ELCP) 9328 Draft British Standard code of practice for earthing. British Standards Institution.

Indian Electricity Rules, 1956.

0.8 Assistance has also been rendered by the Geological Survey of India in collecting the resistivity values of soils of different parts of the country.

0.9 This code is one of the series of Indian Standard codes of practice on installation and maintenance of power equipment. The other codes in this series are:

IS : 732-1963 Code of practice for electrical wiring installations (system voltage not exceeding 650 volts) (*revised*)

IS : 900-1965 Code of practice for installation and maintenance of induction motors (*revised*)

IS : 1255-1958 Code of practice for installation and maintenance of paper-insulated power cables (up to and including 33 kV)

IS : 1866-1961 Code of practice for maintenance of insulating oil

IS : 1886-1961 Code of practice for installation and maintenance of transformers

IS : 2274-1963 Code of practice for electrical wiring installations (system voltage exceeding 650 volts)

IS 2309-1963 Code of practice for the protection of buildings and allied structures against lightning

IS : 3072 (Part I)-1965 Code of practice for installation and maintenance of switchgear : Part I Switchgear (system voltage not exceeding 1 000 V)

IS : 3106-1966 Code of practice for selection, installation and maintenance of fuses (voltages not exceeding 650 volts)

0.10 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

---

1. SCOPE

1.1 This code covers general requirements associated with both system earthing and equipment earthing. It also covers specific requirements for earthing in buildings, industrial locations, generating stations and substations and earthing of overhead lines and miscellaneous apparatus.

1.2 Earthing in mines and of traction equipment and protective earthing against leakage are beyond the scope of this code.

SECTION I TERMINOLOGY AND GENERAL REQUIREMENTS

2. TERMINOLOGY

2.0 For the purpose of this standard, the following definitions shall apply.

2.1 Apparatus — Electrical apparatus including all machines, appliances and fittings in which conductors are used or of which they form a part.

2.2 Arc-Suppression Coil (Petersen Coil) — An earthing reactor so designed that its reactance is such that the reactive current to earth under fault conditions balances the capacitance current to earth flowing from the line so that the earth current at the fault is limited to practically zero.

2.3 Bond — To connect together electrically two or more conductors or metal parts.

2.4 Cable, Armoured — A cable provided with a wrapping of metal (usually in the form of tape or wire), serving as a mechanical protection.

*Rules for rounding off numerical values (*revised*).

2.5 Cable, Flexible — A cable containing one or more cores, each formed of a group of wires, the diameters of the cores and of the wires being sufficiently small to afford flexibility.

2.6 Cable, Metal-Sheathed — An insulated cable with a metal sheath.

2.7 Cut-Out — Any appliance for automatically interrupting the transmission of energy through any conductor when the current rises above a predetermined amount; it shall also include fusible cut-out.

2.8 Damp Situation — A situation in which moisture is either permanently present, or intermittently present to such an extent as to be likely to impair the insulation of an installation conforming to the requirements for ordinary situations.

2.9 Dead — ' Dead ' means at or about earth potential and disconnected from any live system.

2.10 Distributor (Distributing Main) — The portion of any main which is used or intended to be used for the purpose of giving origin to service lines for the purpose of general supply.

2.11 Earth — A connection to the general mass of earth by means of an earth electrode. An object is said to be ' earthed ' when it is electrically connected to an earth electrode; and a conductor is said to be ' solidly earthed ' when it is electrically connected to an earth electrode without intentional addition of resistance or impedance in the earth connection.

2.12 Earth Continuity Conductor — The conductor, including any clamp, connecting to the earthing lead or to each other those parts of an installation which are required to be earthed. It may be in whole or in part the metal conduit or the metal sheath or armour of the cables, or a special continuity conductor, cable or flexible cord incorporating such a conductor.

2.13 Earth Current — A current flowing to earth.

2.14 Earth Electrode — A metal plate, pipe or other conductor or an array of conductors electrically connected to the general mass of the earth.

2.15 Earth Fault — Live portion of a system getting accidentally connected to earth.

2.16 Earth Terminal (Earthing Terminal) — A terminal provided on a piece of apparatus for the purpose of making a connection to earth.

2.17 Earth Wire — A conductor connected to earth and usually situated in proximity to the associated line conductors.

2.18 Earthed Circuit — A circuit one or more points of which are intentionally connected to earth.

2.19 Earthed Pole — That pole or line of an earthed circuit which is connected to earth.

2.20 Earthed System — A system in which the neutral or any one conductor is deliberately connected to earth directly or through an impedance.

2.21 Earthing Lead — The conductor by which the connection to the earth electrode is made.

2.22 Earthing Ring (or Earth Bus) — A ring or bus formed by connecting earth electrodes.

2.23 Earthing Resistor (Earthing Resistance) — A resistor through which a system is earthed and which serves to limit the current flowing in the event of an earth fault.

2.24 Fault — Any defect in plant, apparatus or conductor, which impairs normal operation or safety.

2.25 Fault Current — A current flowing from one conductor to earth, or to another conductor, owing to a fault in the insulation.

2.26 Feeder — A line which supplies a point of a distributing network without being tapped at any intermediate point.

2.27 Fuse — A device that, by the fusion of one or more of its specially designed and proportioned components, opens the circuit in which it is inserted when the current through it exceeds a given value for a sufficient time. The fuse comprises all the parts that form the complete device.

2.28 Insulation

2.28.1 *Double Insulation* — Denotes insulation comprising both functional insulation and supplementary insulation.

2.28.2 *Functional Insulation* — Denotes the insulation necessary for the proper functioning of equipment and for basic protection against electric shock.

2.28.3 *Reinforced Insulation* — Denotes an improved functional insulation with such mechanical and electrical qualities that it provides the same degree of protection against electric shocks as double insulation.

2.28.4 *Supplementary Insulation (Protective Insulation)* — Denotes an independent insulation provided in addition to the functional insulation in order to ensure protection against electric shock in case of failure of the functional insulation.

2.29 Leakage — The passage of electricity in a path, other than that desired, due to imperfect insulation.

2.30 Leakage Current — A fault current of relatively small value, as distinguished from that due to a short-circuit.

2.31 Live (or Alive) — An object is said to be 'live' when a difference of potential exists between it and earth.

2.32 Middle Wire — That conductor of three-wire system which is intermediate in voltage between the other two.

2.33 Minimum Fusing Current (of a Fuse) — The minimum current at which a fuse element shall melt, that is, the asymptotic value of current shown by the curve of total operating time.

2.33.1 In practice, this is deemed to be the value of the current corresponding (on the curve) to an arbitrary time sufficiently long for the asymptotic value to be nearly reached.

2.34 Multiple Earthed Neutral System — A system of earthing in which the parts of an installation specified to be earthed are connected to the general mass of earth and in addition, are connected within the installation to the neutral conductor of the supply system.

2.35 Network — An aggregation of conductor intended for the distribution of electrical energy.

2.36 Neutral Point (Neutral)

2.36.1 *Of a System* — That point which has the same potential as the point of junction of a group of equal resistances, connected at their free ends to the appropriate main terminals or lines of the system. The number of such resistances is 2 for single-phase, 4 for 2-phase (applicable to 4-wire systems only) and 3 for 3-phase systems.

2.36.2 *Of a Symmetrical System* — The point with respect to which the potential of the conductors is symmetrical. It is usually connected to earth.

2.36.3 *Of a Single-Phase System* — The term 'neutral' is used in relation to single-phase systems in this code to denote that conductor which is connected with earth at one or more points.

2.37 Pilot (Pilot Cable) — An auxiliary line intended for measurements, signals or protection in an electrical network.

2.38 Potential (at a Point) — The potential difference between that point and earth.

2.39 Potential Gradient (at a Point) — The potential difference per unit length measured in the direction in which it is maximum.

2.40 Protective System — A system consisting of apparatus and connections responsive to a disturbance (overvoltage, current surge, fault to earth, etc) protecting an electrical installation against the harmful effects which may result therefrom, by isolating the faulty section.

2.41 Resistance Area (of an Earth Electrode only) — The area of earth (around earth electrode) within which practically the whole of the potential difference between the electrode and the general mass of earth occurs when it is carrying an earth fault or test current.

2.42 Service Line — Any electric line through which energy may be supplied by the supply authorities to a consumer either from any distributor or directly from the premises of the supply authorities.

2.43 Step Potential — The maximum value of the potential difference possible of being shunted by a human body between two accessible points on the ground separated by the distance of one pace which may be assumed to be one metre.

2.44 Touch Potential — The maximum value of potential difference between a point on the ground and a point on an object likely to carry fault current such that the points can be touched by a person.

2.45 Voltage, Extra-Low — A voltage normally not exceeding 32 volts under normal conditions.

2.46 Voltage, Low* — A voltage normally exceeding extra low voltage, but not exceeding 250 volts rms alternating current or direct current under normal conditions.

2.47 Voltage, Medium — A voltage normally exceeding 250 volts, but not exceeding 650 volts rms alternating current or direct current under normal conditions.

2.48 Voltage, High — A voltage normally exceeding 650 volts under normal conditions.

3. EXCHANGE OF INFORMATION

3.1 When the earthing of a consumer's installation is being planned, prior consultation should take place between the consultant or contractor and the supply authority. Where necessary, consultation with posts and telegraphs department shall also be carried out in order to avoid any interference with telecommunication system.

4. GENERAL REQUIREMENTS

4.1 Earthing shall generally be carried out in accordance with the requirements of Indian Electricity Rules, 1956 as amended from time to time and the relevant regulations of the Electricity Supply Authority concerned. The following Indian Electricity Rules are particularly applicable:

32, 51, 61, 62, 67, 69, 88 (2) and 90.

*For the purpose of this code, the term 'low voltage' is held to include medium voltage unless specifically stated otherwise.

4.1.1 Extracts from Indian Electricity Rules, 1956 as amended up to 14 July 1966 referred to in this code are given in Appendix A.

4.2 All medium voltage equipment shall be earthed by two separate and distinct connections with earth through an earth electrode (*see* Appendix A, Rule No. 61). In the case of high and extra high voltages the neutral points shall be earthed by not less than two separate and distinct connections with earth each having its own electrode at the generating station or substation and may be earthed at any other point provided no interference is caused by such earthing. If necessary, the neutral may be earthed through a suitable impedance.

4.2.1 In cases where direct earthing may prove harmful rather than provide safety (for example, high frequency and mains frequency coreless induction furnaces), relaxation may be obtained from the competent authority (*see also* **15.3.5**).

4.3 Earth electrodes shall be provided at generating stations, substations and consumer premises in accordance with the requirements.

4.4 As far as possible all earth connections shall be visible for inspection.

4.5 All connections shall be carefully made; if they are poorly made or inadequate for the purpose for which they are intended, loss of life or serious personal injury may result.

4.6 Each earth system shall be so devised that the testing of individual earth electrode is possible. It is recommended that the value of any earth system resistance shall not be more than 5 ohms, unless otherwise specified (*see* **5.1.3**, **5.5**, **12.1.2** and **17.2.10**).

4.7 The minimum size of earthing lead used on any installation shall have a nominal cross-sectional area of not less than 3·0 mm^2 if of copper and 6 mm^2 if of galvanized iron or steel. The actual size will depend on the maximum fault current which the earthing lead will be required to carry safely (*see* **9.2.4**).

4.8 It is recommended that a drawing showing the main earth connection and earth electrodes be prepared for each installation.

4.9 No addition to the current-carrying system either temporary or permanent, shall be made, which will increase the maximum available earth fault current or its duration until it has been ascertained that the existing arrangement of earth electrodes, earth bus-bar, etc, are capable of carrying the new value of earth fault current which may be obtained by this addition.

4.10 No cut-out, link or switch other than a linked switch arranged to operate simultaneously on the earthed or earthed neutral conductor and the live conductors, shall be inserted on any supply system. This, however, does not include the case of a switch for use in controlling a generator or a transformer or a link for test purposes (*see* Appendix A, Rule No. 32).

4.11 All materials, fittings, etc, used in earthing shall conform to Indian Standard specifications wherever these exist. In the case of materials for which Indian Standard specifications do not exist, the material shall be approved by the competent authority.

NOTE — A list of Indian Standards required for reference for earthing is given in Appendix B.

5. DESIGN CONSIDERATIONS

5.1 System Earthing

5.1.1 The question of how a system shall be earthed is governed by the Indian Electricity Rules, 1956.

5.1.2 The regulations that every medium, high and extra high voltage equipment shall be earthed by not less than two separate and distinct connections with earth is designed primarily to preserve the security of the system by ensuring that the voltage on each live conductor is restricted to such a value with respect to the potential of the general mass of the earth as is consistent with the level of insulation applied.

5.1.3 The earth system resistance should be such that when any fault occurs against which earthing is designed to give protection, the protective gear will operate to make the faulty portion of plant harmless. In most cases such operation involves isolation of the faulty main or plant by circuit-breaker or fuses. In the case of underground system there may be no difficulty, but in the case of overhead line system protected only by fuses there may be difficulty in so arranging the value of the earth resistance that a conductor falling and making good contact with earth shall cause the fuses in the supply to operate.

5.1.4 Earthing may not give protection against faults which are not essentially earth faults. For example, if a phase conductor of an overhead spur line breaks, and the part remote from the supply falls to the ground, it is unlikely that any protective gear relying on earthing will operate since the major fault is the open-circuit against which earthing gives no protection.

5.2 Equipment Earthing

5.2.1 Earthing of all metal work of electrical equipment other than parts which are normally live or current carrying shall be carried out and shall conform to Indian Electricity Rules, 1956.

5.2.2 The object of equipment earthing is to ensure effective operation of the protective gear in the event of leakage through such metal work, the potential of which with respect to neighbouring objects may attain a value which would cause danger to life or risk of fire.

5.3 Soil Resistivity

5.3.1 The resistance to earth of an electrode of given dimensions is dependent on the electrical resistivity of the soil in which it is installed. It follows, therefore, that an overriding consideration in deciding which of the alternative method of protection is to be adopted for a particular system or location is the soil resistivity in the area concerned.

5.3.2 The type of soil largely determines its resistivity and representative values for soils generally found in India are given in Appendix C. Earth conductivity is, however, essentially electrolytic in nature and is affected therefore by moisture content of the soil and its chemical composition and concentration of salts dissolved in the contained water. Grain size and distribution and closeness of packing are also contributory factors since they control the manner in which the moisture is held in soil. Many of these factors vary locally and some seasonally and, therefore, the values given in Appendix C should be taken only as a general guide. Local values should be verified by actual measurement and this is specially important where the soil is stratified, as owing to the disposition of earth current, the effective resistivity depends not only on the surface layers but also on the underlying geological formation.

5.3.3 The soil temperature also has some effect on soil resistivity but is important only near and below freezing point, necessitating the installation of earth electrode at depths to which frost will not penetrate.

5.3.4 While the fundamental nature and properties of a soil in a given area cannot be changed, use can be made of purely local conditions in choosing suitable electrode sites and of methods of preparing the site selected, to secure optimum resistivity. These measures may be summarized as follows:

5.3.4.1 Where there is any option, a site should be chosen in one of the following types of soil in order of preference.

a) Wet marshy ground and grounds containing refuse, such as ashes, cinders and brine waste;
b) Clayey soil or loam mixed with small quantities of sand;
c) Clay and loam mixed with varying proportions of sand, gravel and stone; and
d) Damp and wet sand pit.

5.3.4.2 A site should be chosen which is naturally not well drained. A water logged situation, however, is not essential unless the soil be sand or gravel as in general no advantage results from an increase in moisture content above about 15 percent to 25 percent. Perennial wells may also be used as sites for earth electrodes with advantage where the bottom of the earth is rocky.

5.3.4.3 Electrodes should preferably be situated in a soil which has a fine texture and which is packed by watering and ramming as tightly as possible. Where practicable the soil should be sifted and all lumps should be broken up and stones removed in the immediate vicinity of the electrodes.

5.3.4.4 Recourse may be had to chemical treatment of soil to improve the conductivity. Common salt is generally used for this purpose and the addition of less than one part by weight of salt to 200 of soil moisture has been found to reduce the resistivity by 80 percent but there is little advantage in increasing the salt content above 3 percent (*see* **17.2.11**). Calcium chloride, sodium carbonate and other substances too have been found beneficial. But before chemical treatment is applied, it should be verified that no deleterious effect on the electrode material will result.

5.3.4.5 Use should be made, where possible, of natural salts in soils produced by bacteriological action on decaying plants. The resistivity of soil on which plants are growing will be lower than that of the same soil in the absence of plants.

5.3.4.6 In places where the soil conditions appear to be extensively corrosive, the soil may be chemically examined before deciding the material of the earth electrode.

5.3.5 *Effect of Moisture Content on Earth Resistivity* — Moisture content is one of the controlling factors in earth resistivity. Fig. 1 shows the variation of resistivity of red clay soil with percentage of moisture. The moisture content is expressed in percent by weight of the dry soil. Dry earth weighs about 1 440 kg per cubic metre and thus 10 percent moisture content is equivalent to 144 kg of water per cubic metre of dry soil. It will be seen from Fig. 1 that above about 20 percent moisture the resistivity is very little affected, while below 20 percent the resistivity increases very abruptly with the decrease in moisture content. A difference of a few percent moisture will therefore make a very marked difference in the effectiveness of earth connection if the moisture content falls below 20 percent. The normal moisture content of soils ranges from 10 percent in dry seasons to 35 percent in wet seasons, and an approximate average may be perhaps 16 to 18 percent.

It should be recognized, however, that moisture alone is not the predominant factor in the low resistivity of soils; for example, earth electrodes driven directly in the beds of rivers or mountain streams may present very high resistance to earth. If the water is relatively pure it will be of high resistivity and unless the soil contains sufficient natural elements to form a conducting electrolyte, the abundance of water will not provide the soil with adequate conductivity. The value of high moisture content

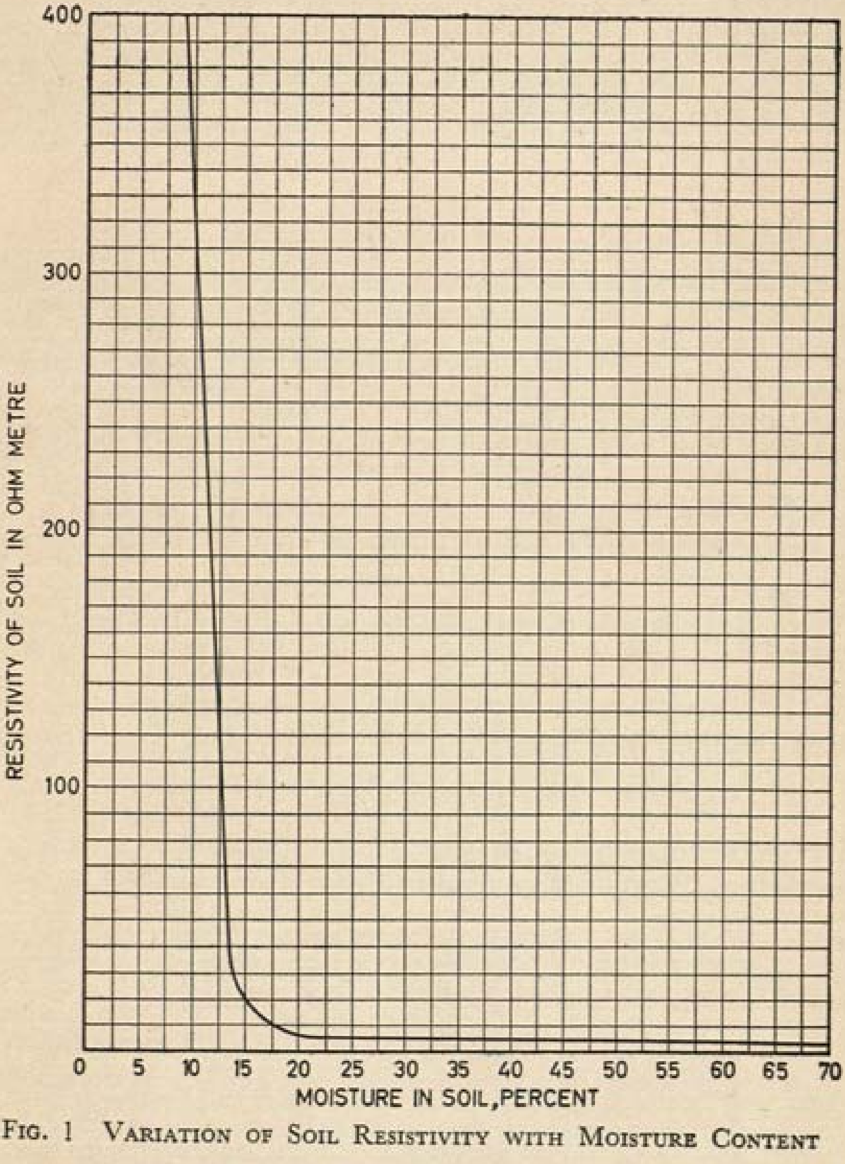


FIG. 1 VARIATION OF SOIL RESISTIVITY WITH MOISTURE CONTENT

in soils is advantageous in increasing the solubility of existing natural elements in the soil, and in providing for the solubility of ingredients which may be artificially introduced to improve the soil conductivity.

5.3.6 *Effect of Temperature on Earth Resistance* — The temperature coefficient of resistivity for soil is negative, but is negligible for temperatures above freezing point. At about 20°C, the resistivity change is about 9 percent per degree celsius. Below 0°C the water in the soil begins to freeze and introduces a tremendous increase in the temperature coefficient, so that as the temperature becomes lower the resistivity rises enormously. It is, therefore, recommended that in areas where the temperature is expected to be quite low, the earth electrodes should be installed well below the frost line. Where winter seasons are severe this may be about 2 metre below the surface, whereas in mild climates the frost may penetrate only a few centimetres or perhaps the ground may not freeze at all. Earth electrodes which are not driven below the frost depth may have a very great variation in resistance throughout the seasons of the year. Even when driven below the frost line there is some variation, because the upper soil when frozen presents a decided increase in soil resistivity and has the effect of shortening the active length of electrode in contact with soil of normal resistivity.

5.3.7 *Artificial Treatment of Soil* — Multiple rods even in large number may sometime fail to produce an adequately low resistance to earth. This condition arises in installations involving soils of high resistivity. The alternative is to reduce the resistivity of the soil immediately surrounding the earth electrode. To reduce the soil resistivity, it is necessary to dissolve in the moisture, normally contained in the soil, some substance which is highly conductive in its water solution. The most commonly used substances are sodium chloride ($NaCl$), also known as common salt, calcium chloride ($CaCl_2$), sodium carbonate (Na_2CO_3), copper sulphate ($CuSO_4$), salt and soft coke and salt and charcoal in suitable proportions.

5.3.7.1 With average or high moisture content these agents form a conducting electrolyte throughout a wide region surrounding the earth electrode. Approximately 90 percent of the resistance between a driven rod and earth lies within a radius of about two metres from the rod. This should be kept in mind when applying the agents for artificial treatment of soil. The simplest application is by excavating a shallow basin around the top of the rod, one metre in diameter and about 30 cm deep, and applying the artificial agent in this basin. The basin should subsequently be filled several times with water, which should be allowed each time to soak into the ground, thus carrying the artificial treatment, in electrolyte form, to considerable depths and allowing the artificial agent to become diffused throughout the greater part of the effective cylinder of earth surrounding the driven rod.

5.3.7.2 The reduction in soil resistivity effected by salt is shown by the curve in Fig. 2. The salt content is expressed in percent by weight of the contained moisture. It will be noted that the curve flattens off at about 5 percent salt content and a further increase in salt gives but little decrease in the soil resistivity. The effect of salt will be different for different kinds of soil and for various moisture contents but the curve will convey an idea of how the soil conductivity can be improved. Decreasing the soil resistivity causes a corresponding decrease in the resistance of a driven earth electrode.

5.3.7.3 In close texture soils, the artificial treatment may be effective over a period of many years. However, it is recommended that annual or bi-annual measurements of earth resistivity should be made to find out if additional treatment is needed.

5.3.7.4 In using artificial treatment the possible corrosive effect of the salt on the driven rods and connections should be considered. The possible contamination of the domestic water supply should also be considered.

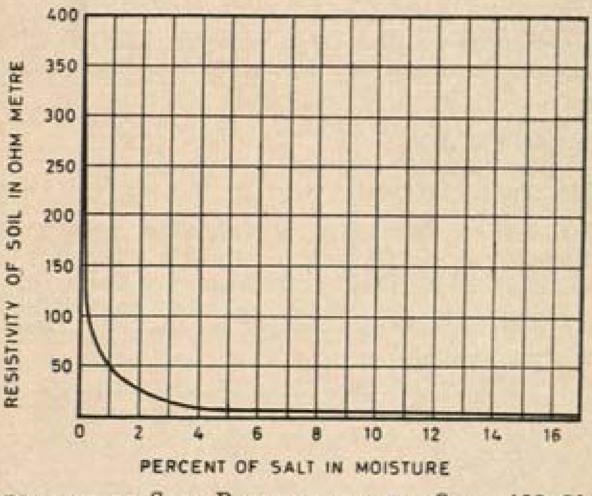


FIG. 2 VARIATION OF SOIL RESISTIVITY WITH SALT (NaCl) CONTENT, CLAY-SOIL HAVING 3 PERCENT MOISTURE

5.4 Potential Gradients — It is necessary to ensure, especially in case of large electrical installations, that a person walking on the ground or touching an earthed object, in or around the premises shall not have large dangerous potential differences impressed across his body in case of a fault within or outside the premises. Such danger may arise if steep potential gradients exist within the premises or between boundary of the premises and an accessible point outside. For this the step potential and touch potential should be investigated and kept within safe limits. Within a earthing grid, the step and touch potentials may be lowered to any value by reducing the mesh interval of the grid. The situation is more difficult in the zone immediately outside the periphery where the problem may exist even for the theoretical case of a single plate covering the substation area. This problem may be serious in small stations where the grid may cover only a limited area. Attempts should be made to design a substation so as to eliminate the possibility of touch contact beyond the earth-system periphery, when the limitations on step potential become less exacting. While assessing the touch potential, the method of earthing of the object touched, for example, whether it is earthed directly below or remotely should be kept in view in order to consider the possibility of occurrence of large potential differences.

Special attention should be paid to the points near the operating handles of apparatus and, if necessary, potential equaliser grillages of closer mesh securely bonded to the structure and the operating handle should be buried below the surface where the operator may stand when operating the switch.

5.5 At consumer's premises where the apparatus is protected by fuses, the total earth circuit impedance shall not be more than that obtained by graphs of Fig. 3.

6. EARTH ELECTRODES

6.1 Earth Electrode Meterial

6.1.1 Although electrode material does not affect initial earth resistance, care should be taken to select a material which is resistant to corrosion in the type of soil in which it will be used.

6.1.2 Under ordinary conditions of soil, use of copper, iron or mild steel electrodes is recommended.

6.1.3 In cases where soil conditions point to excessive corrosion of the electrode and the connections, it is recommended to use either copper electrode or copper clad electrode or zinc coated (galvanized) iron electrodes.

6.1.4 In direct current system, however, due to electrolytic action which causes serious corrosion, it is recommended to use only copper electrodes.

6.1.5 The electrode shall be kept free from paint, enamel and grease.

6.1.6 It is recommended to use similar material for earth electrodes and earth conductors or otherwise precautions should be taken to avoid corrosion.

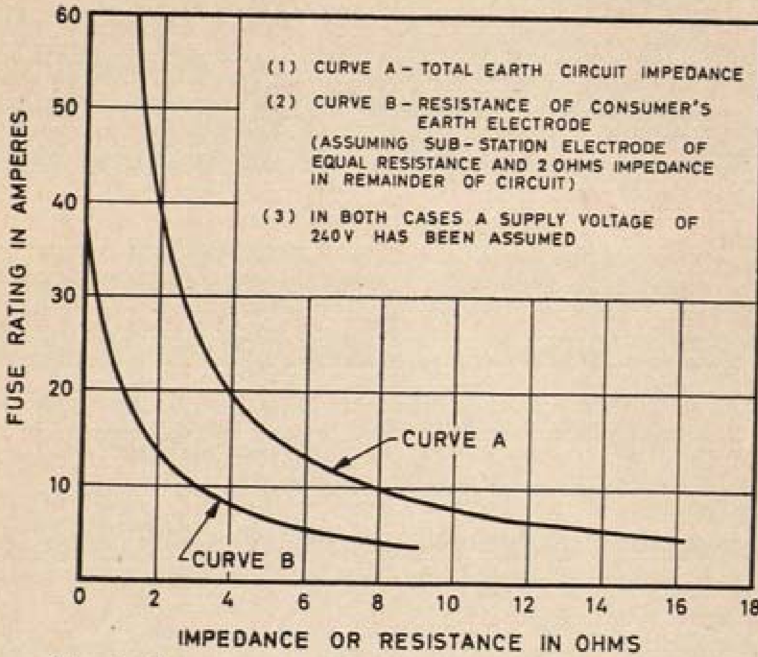


FIG. 3 RECOMMENDED EARTH CIRCUIT IMPEDANCE OR RESISTANCE FOR DIFFERENT VALUES OF FUSE RATING

6.2 Current Loading of Earth Electrodes

6.2.1 An earth electrode should be designed to have a loading capacity adequate for the system for which it forms a part, that is, it should be capable of dissipating without failure, energy in the earth path at the point at which it is installed under any condition of operation on the system. Failure is fundamentally due to excessive rise of temperature at the surface of the electrode and is thus a function of current density and duration as well as electrical and thermal properties of soil.

6.2.2 Generally soils have a negative temperature coefficient of resistance so that sustained current loading results in an initial decrease in electrode resistance and a consequent rise in the earth fault current for a given applied voltage. As soil moisture is driven away from the soil electrode interface, the resistance increases and will ultimately become infinite if the temperature-rise is sufficient. This occurs in the region of 100°C and results in complete failure of the electrode.

6.2.3 Two conditions of operation require consideration, namely:

a) Long duration overloading as with normal system operation, and

b) Short time overloading as under fault conditions in directly earthed system.

6.2.3.1 Long duration overloading due to normal unbalance of the system will not canse failure of earth electrodes provided that the current density at the electrode surface does not exceed 40 A/m^2. Limitation to value below this would generally be imposed by the necessity to secure a low resistance earth.

6.2.3.2 Time taken by an earth electrode to fail on short time overload is inversely proportional to the specific loading which is given by $I^2\rho$ where I is the current density at the electrode surface in A/m^2, and ρ the resistivity of the soil in ohm metre. The maximum permissible current density is given by

$$I = \frac{7{\cdot}57 \times 10^3}{\sqrt{\rho t}} \text{ A/m}^2$$

where

t = duration of earth fault in seconds.

6.3 Voltage Gradient Around Earth Electrodes

6.3.1 Under fault conditions the earth electrode is raised to a potential with respect to the general mass of the earth. This results in the existence of voltages in the soil around the electrode which may be injurious to telephone and pilot cables whose cores are substantially at earth potential owing to the voltage to which the sheaths of such cables are raised. The voltage gradient at the surface of the earth may also constitute danger to life. The former risk arises mainly in connection with large electrode systems, as at power stations and substations.

6.3.2 Danger to life occurs principally with pole-mounted substations on low-voltage systems. In rural areas it is by no means uncommon for the earth-path resistance to be such that faults are not cleared within a short period. The same trouble sometimes occurs at factories and farms where earth electrodes are provided for individual appliances. An effective remedy is to earth the neutral conductor at some point on the system inaccessible to human and animals, rather than earthing the neutral at the transformer itself. Alternatively, in the case of wood-pole lines, pipe or rod electrodes may be buried with their tops below the surface of the soil and connection made to them by means of insulated leads. The maximum voltage gradient over a span of 2 m, adjacent to a 2·5-cm diameter pipe electrode is reduced from 85 percent with the top of the electrode at ground level to nearly 20 percent and 5 percent with it buried 30 cm and 1 m respectively below the ground level.

6.3.3 Earth electrodes should not be installed in proximity to a metal fence to avoid the possibility of the fence becoming live, and thus dangerous at points remote from the substation, or alternatively giving rise to danger within the resistance area of the electrode which can be reduced only by introducing a good connection with the general mass of the earth. If the metal fence is unavoidable, it should be earthed.

7. TYPES OF EARTH ELECTRODES

7.1 Rod and Pipe Electrodes (Fig. 4)

7.1.1 These electrodes shall be made of metal rod or pipe having a clean surface not covered by paint, enamel or poorly conducting material.

7.1.2 Rod electrodes of steel or galvanized iron shall be at least 16 mm in diameter and those of copper shall be at least 12·5 mm in diameter.

7.1.3 Pipe electrodes shall not be smaller than 38 mm internal diameter if made of galvanized iron or steel and 100 mm internal diameter if made of cast iron.

7.1.4 Electrodes shall, as far as practicable, be embedded below permanent moisture level.

7.1.5 The length of rod and pipe electrodes shall not be less than 2·5 m.

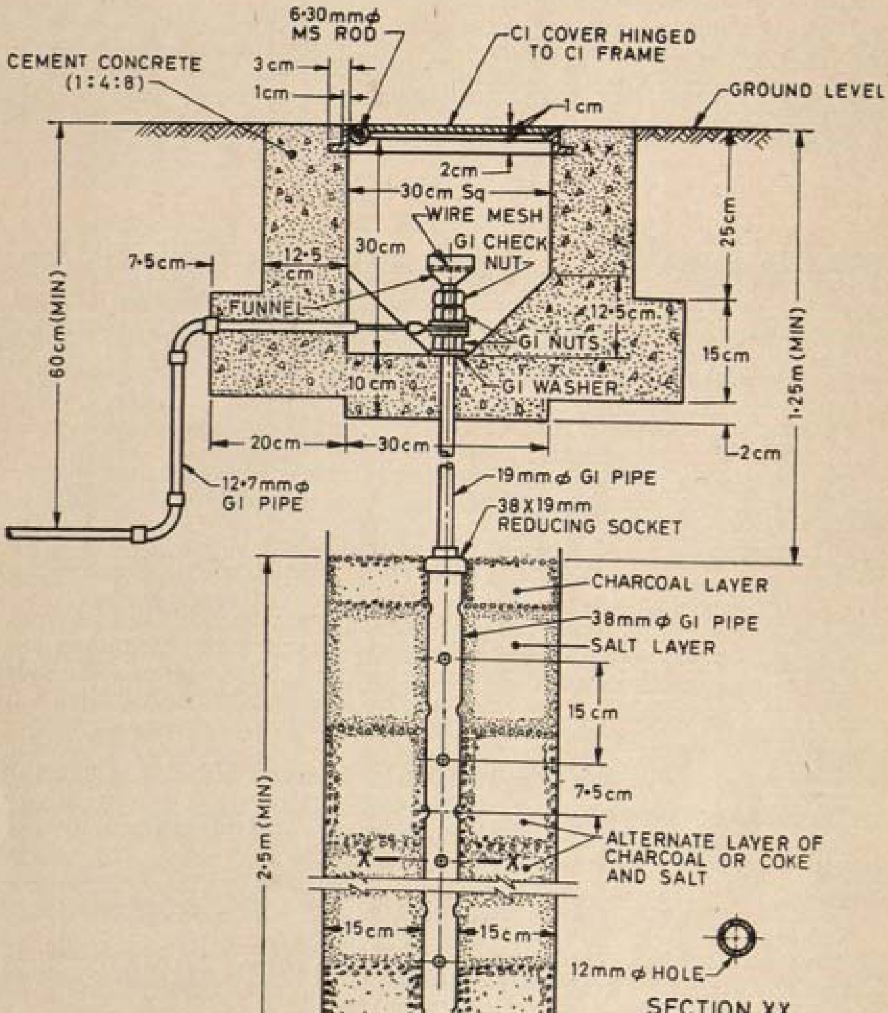
7.1.6 Except where rock is encountered pipes and rods shall be driven to a depth of at least 2·5 m. Where rock is encountered at a depth of less than 2·5 m, the electrodes may be buried inclined to the vertical. In this case too the length of the electrodes shall be at least 2·5 m and inclination not more than 30° from the vertical.

7.1.7 Deeply driven pipes and rods are, however, effective where the soil resistivity decreases with depth or where substratum of low resistivity occurs at depth greater than those to which rods and pipes are normally driven.

7.1.8 Pipes or rods, as far as possible, shall be of one piece.

7.1.9 For deeply driven rods, joints between sections shall be made by means of a screwed coupling which should not be of greater diameter than that of the rods which it connects together.

7.1.10 To reduce the depth of burial of an electrode without increasing the resistance, a number of rods or pipes shall be connected together in parallel. The resistance in this case is practically proportional to the reciprocal of the number of electrodes used so long as each is situated outside the resistance area of the other (*see* Fig. 5). The distance between two electrodes in such a case shall preferably be not less than twice the length of the electrode.



NOTE — Three or four buckets of water to be poured into sump every few days to keep the soil surrounding the earth pipe permanently moist.

FIG. 4 PIPE ELECTRODE

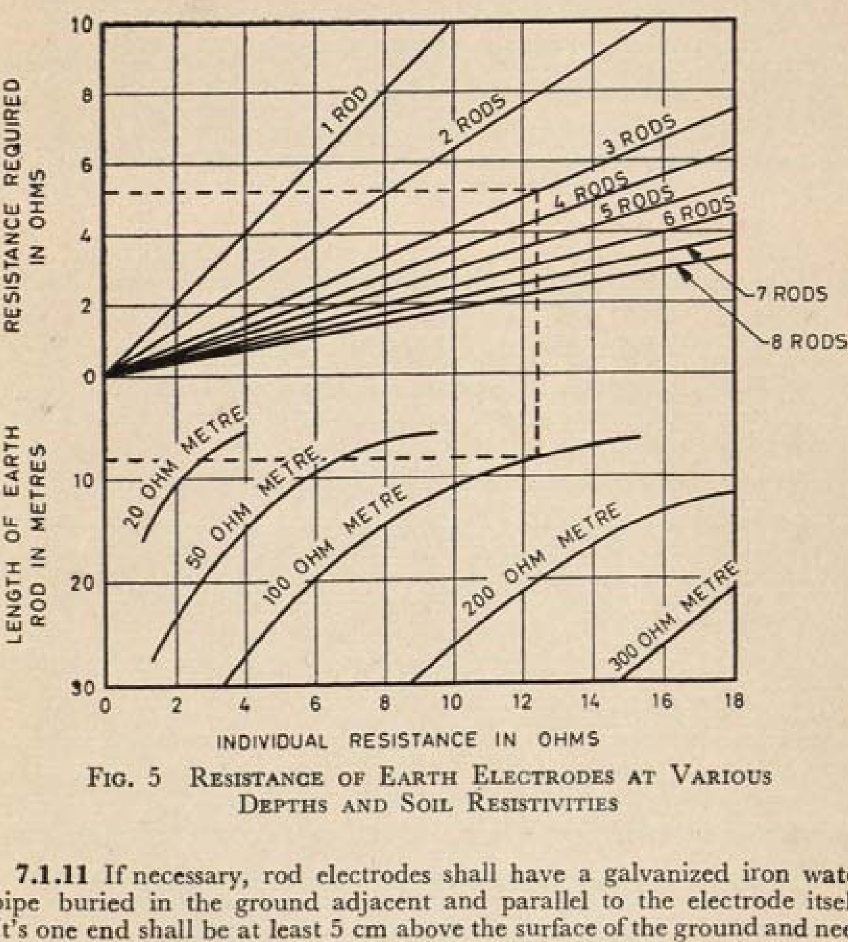


FIG. 5 RESISTANCE OF EARTH ELECTRODES AT VARIOUS DEPTHS AND SOIL RESISTIVITIES

7.1.11 If necessary, rod electrodes shall have a galvanized iron water pipe buried in the ground adjacent and parallel to the electrode itself. It's one end shall be at least 5 cm above the surface of the ground and need not be more than 10 cm. The diameter of the pipe shall be between 5 cm and 10 cm. The difference between the lengths of the electrode and that of the pipe if under the earth's surface shall not be more than 30 cm and in no case shall the length of the pipe exceed that of the electrode.

7.2 Strip or Conductor Electrodes

7.2.1 Strip electrodes shall not be smaller than 25 mm × 1·60 mm if of copper and 25 mm × 4 mm if of galvanized iron or steel. If round conductors are used as earth electrodes their cross-sectional area shall not be smaller than 3·0 mm^2 if of copper and 6 mm^2 if of galvanized iron or steel.

7.2.2 The length of buried conductor shall be sufficient to give the required earth resistance. It shall, however, be not less than 15 m.

7.2.3 These shall be buried in trenches or ditches not less than 0·5 m deep.

7.2.4 The electrodes shall be as widely distributed as possible, preferably in a single straight or circular trench or in a number of trenches radiating from a point.

7.2.5 If the conditions necessitate use of more than one strip, they shall be laid either in parallel trenches or in radial trenches.

7.3 Plate Electrodes (Fig. 6)

7.3.1 Plate electrodes when made of galvanized iron or steel shall be not less than 6·30 mm in thickness. Plate electrodes of copper shall be not less than 3·15 mm in thickness.

7.3.2 Plate electrodes shall be of size at least 60 cm × 60 cm.

7.3.3 Plate electrodes shall be buried such that its top edge is at a depth not less than 1·5 m from the surface of the ground.

7.3.4 Where the resistance of one plate electrode is higher than the required value, two or more plates shall be used in parallel. In such a case two plates shall be separated from each other by not less than 8·0 m.

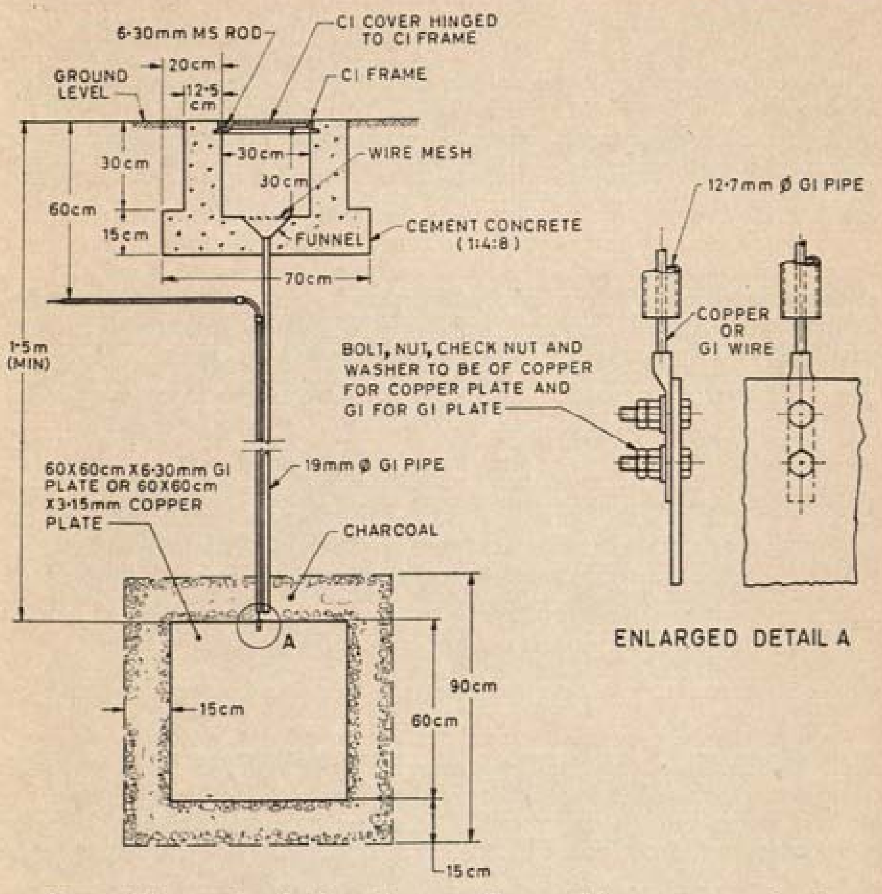
7.3.5 Plates shall preferably be set vertically.

7.3.6 Use of plate electrode is recommended only where the current carrying capacity is the prime consideration, for example, in generating stations and substations.

7.3.7 If necessary, plate electrodes shall have a galvanized iron water pipe buried vertically and adjacent to the electrode. One end of the pipe shall be at least 5 cm above the surface of the ground and need not be more than 10 cm. The internal diameter of the pipe shall be at least 5 cm and need not be more than 10 cm. The length of pipe if under the earth's surface shall be such that it should be able to reach the centre of the plate. In no case, however, shall it be more than the depth of the bottom edge of the plate.

7.4 Cable Sheaths

7.4.1 Where an extensive underground cable system is available, lead sheathed and steel armoured cables may be used as earth electrodes provided the bond across the joints is at least of the same conductivity as of the sheath.



NOTE — Three or four buckets of water to be poured into sump every few days to keep the soil surrounding the earth plate permanently moist.

FIG. 6 PLATE ELECTRODE

7.4.2 The resistance of such an earth electrode system is generally less than 1 ohm.

8. DESIGN OF EARTH ELECTRODES

8.1 Effect of Shape on Electrode Resistance

8.1.1 With electrodes the greater part of the fall in potential occurs in the soil within about 2 m of the electrode surface, since it is here that the current density is highest. To obtain a low overall resistance the current density should be as low as possible in the medium adjacent to the electrode and should decrease rapidly with distance from the electrode.

This requirement is met by making the dimensions in one direction large compared with those in the other two. Thus we find that a pipe, rod or strip will have much lower resistance than a plate of equal surface area. The resistance is not, however, inversely proportional to the surface area of the electrode. The theoretical principles relating to calculation of resistance of earth electrodes are dealt with in **8.1.2**.

8.1.2 The resistance of any electrode buried in the earth is in fact related to the capacitance of that electrode and its image in free space since it can be shown that the lines of current flow are identical with the electrostatic lines of force which would result if the earth were a dielectric and the electrode with its image in the earth's surface were considered as a condenser in free space. This relationship is given by

$$R = \frac{100\,\rho}{4\pi C}$$

where

R = resistance in an infinite medium,

ρ = resistivity of the medium in ohm-metre, and

C = capacitance of the electrode and its image in free space.

8.1.3 In the practical case the medium is divided into two by the plane of earth's surface so that

$$R = \frac{100\,\rho}{2\pi C}$$

Thus if the capacitance in free space of any form of electrode is known together with the resistivity of the surrounding soil, the resistance of the electrode can be calculated. This capacitance is known for some simple forms of electrodes.

Applying this principle, resistance of pipe and rod electrodes, strip electrodes and plate electrodes can be calculated according to **8.2**, **8.3** and **8.4** respectively.

8.2 Rod and Pipe Electrodes — In designing driven rod or pipe electrodes the resistance may be calculated from the following formula:

$$R = \frac{100\,\rho}{2\pi l} \log_e \frac{4l}{d} \text{ ohms}$$

where

ρ = resistivity of soil in ohm-metre,

l = length of rod or pipe in cm, and

d = diameter of rod or pipe in cm.

8.2.1 Consideration of the above formula will show that theoretical resistance to earth of a driven rod electrode depends to a large degree upon its buried length and to a lesser extent upon its diameter.

8.2.2 Figure 7 indicates that when driven in soil of uniform resistivity the resistance of a rod electrode decreases with depth but that there is little to be gained by driving the rod to more than 3 to 3·5 metres.

8.2.3 Figure 7 also indicates that decrease in theoretical resistance with increase in rod diameter is not large. It is therefore recommended to use the rod of such a diameter that can easily withstand the strain of driving.

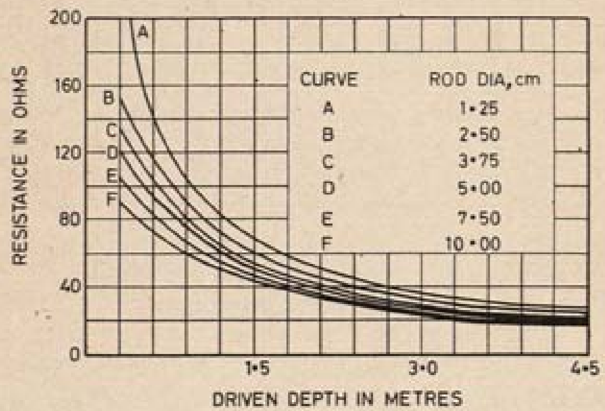


FIG. 7 THEORETICAL VARIATION OF RESISTANCE WITH DEPTH FOR ROD ELECTRODES OF VARIOUS DIAMETERS WITH EARTH RESISTIVITY OF 100 OHM-METRE (ASSUMED UNIFORM)

8.3 Strip Electrodes — In designing strip electrodes, the resistance may be calculated from the following formula:

$$R = \frac{100\,\rho}{2\,\pi\,l} \log_e \frac{288\,l^2}{w\,t} \text{ ohms}$$

where

ρ = resistivity of soil in ohm-metre,

l = length of the strip in cm,

t = width (in the case of strip) or twice the diameter (in the case of round conductors) in cm, and

w = depth of burial of the electrode in cm.

8.3.1 Consideration of the above formula will show that variation in the width of strip or depth of burial have little effect on the resistance value.

8.3.2 It is recommended that the electrodes should be buried at a depth of not less than 0·5 metre.

8.3.3 Figure 8 indicates that the resistance of a strip electrode decreases appreciably with increase in its length.

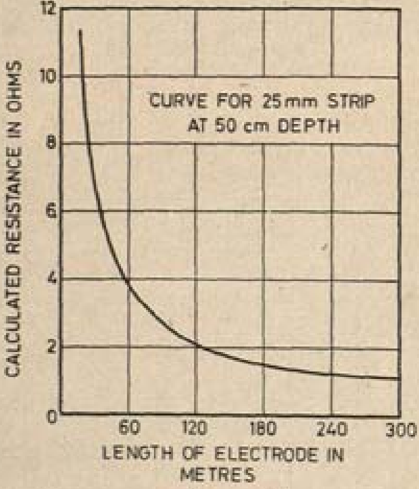


FIG. 8 EFFECT OF LENGTH OF STRIP ELECTRODES ON CALCULATED RESISTANCE FOR SOIL RESISTIVITY OF 100 OHM-METRE (ASSUMED UNIFORM)

8.4 Plate Electrodes — In designing plate electrodes, the resistance may be calculated from the following formula:

$$R = \frac{\rho}{4}\sqrt{\frac{\pi}{A}} \text{ ohms}$$

where

ρ = resistivity of soil in ohm-metre, and
A = area of both sides of plate in cm^2.

8.4.1 In practice little gain is obtained by increasing the plate area of one side by more than 1·75 m^2.

9. EARTH BUS AND EARTH WIRES

9.1 General Requirements

9.1.1 The minimum allowable size of earth wire is determined principally by mechanical consideration for they are more liable to mechanical

AMENDMENT NO. 1 SEPTEMBER 1967

TO

IS : 3043-1966 CODE OF PRACTICE FOR EARTHING

This amendment is being issued to permit the use of aluminium for the purpose of earthing. However, it is emphasized that aluminium should be used only above ground and provided it does not come in contact with walls, floors, etc.

Corrigendum

(*Page* 31, *clause* **9.2.2**, *line* 2) — Substitute 'if' *for* 'is'.

Alterations

(*Page* 13, *clause* **4.7**) — Substitute the following for the existing clause:

'**4.7** Earth continuity conductors and earth wires shall be of copper, galvanized iron or steel or aluminium. The minimum size of these to be used on any installation shall have a nominal cross-sectional area of not less than 3 mm^2 if of copper and 6 mm^2 if of galvanized iron or steel. The actual size will depend on the maximum fault current which they will be required to carry safely (*see* **9.2.4**).

NOTE 1 — The use of aluminium shall be restricted to the portion of the earth conductor above ground and provided it does not come in contact with walls, floors, etc.

NOTE 2 — The minimum size of aluminium earth continuity conductors and earth wires is under consideration.'

(*Page* 31, *clause* **9.1.2**) — Substitute the following for the existing clause:

'All earth wires and earth continuity conductors shall be of copper, galvanized iron or steel or aluminium.'

(*Page* 31, *clause* **9.2.4**) — Substitute the following for the existing clause:

'**9.2.4** The minimum size of copper and aluminium earth wires and earth continuity conductors corresponding to various sizes of

current carrying conductors shall be as follows:

Cross-Sectional Area of Current Carrying Conductor	*Cross-Sectional Area of Earth Continuity Conductor*
mm^2	mm^2
4	4
6	4
10	6
16	10
25	16
35	16
50	25
70	35
95	50
120	70
150	70
185	95
240	120
300	150
400	185

NOTE — The minimum sizes of iron and steel earth wires and earth continuity conductors are under consideration.'

Addenda

(*Page* 31, *clause* **9.2.2**) — Add the following Note at the end of the clause:

'NOTE — The minimum size of aluminium earth wires and earth continuity conductors is under consideration.'

(*Page* 36, *clause* **12.3.2**) — Add the following Note after para 1:

'NOTE — The minimum size of aluminium earth continuity conductors is under consideration.'

(*Page* 36, *clause* **12.4.2**; *Page* 37, *clause* **12.7.2**; *Page* 39, *clause* **14.2.1**; and *Page* 41, *clause* **15.1.1**) — Add the following Note at the end of each clause:

'NOTE — The minimum size of aluminium earth wires is under consideration.'

(*Page* 52, *clause* **17.3.2.3**, *line* 2) — Add the words 'or aluminium' after the words 'or steel'.

(*Page* 52, *clause* **17.3.2.4**) — Add the following Note at the end of the clause:

'NOTE — The minimum size of aluminium earth wires and earth continuity conductors is under consideration.'

(*Page* 52, *clause* **17.3.2.5**, *line* 8) — Add the words 'and aluminium' after the words 'iron and steel'.

Printed at Standard Printing Works, New Delhi-1, India

injury and should therefore be strong enough to resist any strain that is likely to be put upon them.

9.1.2 Every earth wire shall be either of copper, galvanized iron or steel.

9.1.3 They shall be either stranded or solid bars or flat rectangular strips and may be bare provided due care is taken to avoid corrosion and mechanical damage to it.

9.1.4 Interconnections of earth continuity conductors and main and branch earth wires shall be made in such a way that reliable and good electrical connections are permanently ensured.

NOTE — Welded, bolted and clamped joints are permissible. For stranded conductors, sleeve connectors (for example, indented, riveted or bolted connectors) are permissible. Bolted connectors and their screws shall be protected against any possible corrosion.

9.1.5 The path of the earth wire shall, as far as possible, be out of reach of any person.

9.1.6 If the metal sheath and armour have been used as an earth electrode, the armour shall be bonded to the metal sheath and the connection between the earth wire and earthing electrode shall be made to the metal sheath.

9.1.7 If a clamp has been used to provide connection between the earth wire and the metal sheath and armour, it shall be so designed and installed as to provide reliable connection without damage to the cable.

9.1.8 The neutral conductor shall not be used as earth wire.

9.2 Size of Earth Wires

9.2.1 The current carrying capacity of an earth wire is determined by the maximum fault current which it will have to safely carry in the event of failure of insulation and the duration of that current.

9.2.2 No earth wire shall have a cross-sectional area less than 3·0 mm² is of copper and 6 mm² if of galvanized iron or steel except in portable equipment whose current-carrying conductor has a cross-sectional area less than 3·0 mm². In such a case the earth wire should have a cross-sectional area equal to that of current-carrying conductor.

9.2.3 The main earthing ring of any installation shall not be less than 75 mm² in cross-sectional area.

9.2.4 The minimum size of copper earth wire shall be nearly half the size of the corresponding current carrying conductor [*see* also IS : 434 (Part I)-1964* and IS : 692-1965‡]

NOTE — The minimum sizes of iron and steel earth wires are under consideration.

*Specification for rubber-insulated cables Part I: With copper conductors (*revised*).
†Specification for paper-insulated lead-sheathed cables for electricity supply (*revised*).

10. MEASUREMENT OF EARTH ELECTRODE RESISTANCE

10.1 Fall of Potential Method — In this method two auxiliary earth electrodes, besides the test electrode, are placed at suitable distances from the test electrode (*see* Fig. 9). A measured current is passed between the electrode '*A*' to be tested and an auxiliary current electrode '*C*' and the potential difference between the electrode '*A*' and the auxiliary potential electrode '*B*' is measured. The resistance of the test electrode '*A*' is then given by:

$$R = \frac{V}{I}$$

where

R = resistance of the test electrode in ohms,

V = reading of the voltmeter in volts, and

I = reading of the ammeter in amperes.

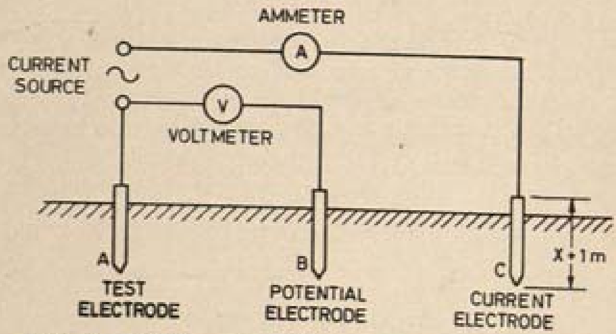


FIG. 9 METHOD OF MEASUREMENT OF EARTH ELECTRODE RESISTANCE

10.1.1 If the test is made at power frequency, that is, 50 c/s, the resistance of the voltmeter should be high compared to that of the auxiliary potential electrode '*B*' and in no case should be less than 20 000 ohms.

NOTE — In most cases there will be stray currents flowing in the soil and unless some steps are taken to eliminate their effect, they may produce serious errors in the measured value. If the testing current is of the same frequency as the stray current, this elimination becomes very difficult and it is better to use an earth tester incorporating a hand-driven generator. These earth testers usually generate direct current and have rotary current-reverser and synchronous rectifier mounted on the generator shaft so that alternating current is supplied to the test circuit and the resulting potentials are rectified for measurement by a direct-reading moving-coil ohm-meter. The presence of stray currents in the soil is indicated by a wandering of the instrument pointer, but an increase or decrease of generator handle speed will cause this to disappear.

10.1.2 The source of current shall be isolated from the supply by a double wound transformer.

10.1.3 At the time of test, where possible, the test electrode shall be separated from the earthing system.

10.1.4 The auxiliary electrodes usually consist of 12·5 mm diameter mild steel rod driven up to 1 m into the ground.

10.1.5 All the test electrodes and the current electrodes shall be so placed that they are independent of the resistance area of each other. If the test electrode is in the form of rod, pipe or plate, the auxiliary current electrode '*C*' shall be placed at least 30 m away from it and the auxiliary potential electrode '*B*' shall be placed midway between them.

10.1.6 Unless three consecutive readings of test electrode resistance with different spacings of electrodes agree the test shall be repeated by increasing the distance between electrodes '*A*' and '*C*' up to 50 m and each time placing the electrode '*B*' midway between them.

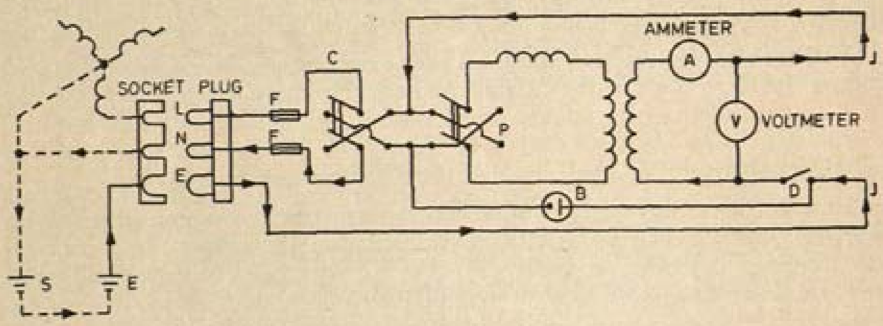
10.2 Alternative Method

10.2.1 The method described in **10.1** may not give satisfactory results if the test electrode is of very low impedance (one ohm or less). This applies particularly, while measuring the combined resistance of large installations. In these cases, the following method may be adopted.

10.2.2 Two suitable directions, at least 90 degrees apart, are first selected. The potential lead is laid in one direction and an electrode is placed 250 to 300 metres from the fence. The current lead is taken in the other direction and the current electrode located at the same distance as the potential electrode. A reading is taken under this condition. The current electrode is then moved out in 30-m steps until the same reading is obtained for three consecutive locations. The current electrode is then left in the last foregoing position and the potential electrode is moved out in 30-m steps until three consecutive readings are obtained without a change in value. The last readings then correspond to the true value of earth resistance.

11. MEASUREMENT OF EARTH LOOP IMPEDANCE

11.1 The current which will flow under earth fault conditions and will thus be available to operate the overload protection depends upon the impedance of the earth return loop. This includes the line conductor, fault, earth-continuity conductor and earthing-lead, earth electrodes at consumer's premises and substations and any parallel metallic return to the transformer neutral as well as the transformer winding. To test the overall earthing for any installation depending for protection on the operation of overcurrent devices, for example, fuses, it is necessary to measure the impedance of this loop under practical fault conditions. After the supply has been connected this shall be done by the use of an earth loop impedance tester as shown in Fig. 10. The neutral is used in place of the phase conductor for the purpose of the test. The open-circuit voltage of the loop tester should not exceed 32 volts.



A = ammeter
B = neon indicator
C = main switch
D = test switch
E = consumer's earth electrode
F = supply fuses
P = polarity switch
S = substation earth electrode
V = voltmeter

At *JJ*, jacks are provided for insertion of plugs for connection to external neutral and/or earth conductors if desired.

Note 1 — Arrows show current flow in neutral/earth loop.

Note 2 — Supply system is shown dotted.

Fig. 10 Circuit Diagram of Earth Loop Impedance Tester

SECTION 2 BUILDINGS, INDUSTRIAL LOCATIONS AND MISCELLANEOUS ELECTRICAL APPARATUS

12. EARTHING OF INSTALLATIONS IN BUILDINGS

12.1 Basic Requirements for Earthing

12.1.1 The installations shall generally be carried out in accordance with the Indian Electricity Rules 1956 as amended from time to time.

12.1.2 The earthing arrangements of the consumer's installation shall be such that on the occurrence of a fault of negligible impedance from a phase or non-earthed conductor to adjacent exposed metal, a current corresponding to not less than three and a half times the rating of the fuse or one and half times the setting of the overload earth leakage circuit-breaker will flow except where voltage operated earth leakage circuit-breakers are used and make the faulty circuit dead. Where fuses are used to disconnect the faulty section of an installation in the event of an earth fault, the total permissible impedance of the earth fault path may be computed from the following formula (for a normal three-phase system with earthed neutral).

$$Z = \frac{\text{Phase-to-earth voltage of system}}{\text{Minimum fusing current of fuse} \times \text{factor of safety}}$$

where

Z = permissible impedance in ohms.

12.1.2.1 The factor of safety in the above formula ensures that in most cases the fuse will blow in a time which is sufficiently short to avoid danger and allowing for a number of circumstances such as the grading of fuse ratings, increase of resistance due to drying out of the earth electrodes in dry weather, inevitable extensions to installations involving increase in length of the circuit conductors and the earth continuity conductors, etc.

12.1.2.2 It will be observed that this requirement determines the overall impedance and does not contain a specific reference to any part of the circuit such as the conduit or other earth continuity conductor together with the earthing lead. In fact, in large installations the overall impedance permissible may be less than 1 ohm, so that considerably less than this might be allowable for the earth continuity system.

12.1.3 It is desirable when planning an installation to consult the supply authority or an electrical contractor having knowledge of local conditions, in order to ascertain which of the two, namely, the use of fuses or overload circuit-breakers, for protection against earth-leakage currents is likely to prove satisfactory.

12.1.4 It is recommended that the maximum sustained voltage developed under fault conditions between exposed metal required to be earthed and the consumer's earth terminal shall not exceed 32 volts rms.

12.2 Earth Electrode — Only pipe or rod earth electrodes are recommended and they shall satisfy the requirements of **6** and **7.1**.

12.3 Earth Continuity Conductors

12.3.1 Connection to earth of those parts of an installation which require to be earthed shall be made by means of an earth continuity conductor which may be a separate earth conductor, the metal sheath of the cables, or the earth continuity conductor contained in a cable, flexible cable or flexible cord. Water pipes shall not, under any circumstances, be used as earth continuity conductors.

12.3.2 *Separate Earth Continuity Conductor* — The cross-sectional area of every separate copper earth-continuity conductor not contained in a cable, flexible cable or flexible cord should be not less than about one-half that of the largest current-carrying conductor feeding the circuit, and in no case shall any separate earth continuity conductor have a cross-sectional area less than 3·0 mm² if of copper and 6 mm² if of galvanized iron or steel. It need not have a cross-sectional area greater than 65 mm² (copper).

The conductance of any earth-continuity conductor installed in lieu of copper shall be equivalent to that of the copper conductor specified. Where an earth-continuity conductor is to be connected to another, their surfaces shall be suitably protected against corrosion.

12.3.3 *Earth Continuity Conductors Contained in Cables* — The cross-sectional area of earth-continuity conductors contained in flexible cables or flexible cords should be equal to that of the current-carrying conductors. Cross-sectional areas of earth-continuity conductors contained in metal, tough rubber or PVC sheathed cables should comply with the appropriate Indian Standards.

12.3.4 *Cable Sheaths Used as Earth Continuity Conductors* — Where the metal sheaths of cables are used as earth-continuity conductors, every joint in such sheaths shall be so made that its current-carrying capacity is not less than that of the sheath itself. Where necessary, they shall be protected against corrosion.

Where non-metallic joint boxes are used, means shall be provided to maintain the continuity, such as a metal strip having a resistance not greater than that of the sheath of the largest cable entering the box.

12.3.5 *Metal Conduit Pipe Used as an Earth Continuity Conductor* — Metal conduit pipe should generally not be used as an earth continuity conductor but where used a very high standard of workmanship in installation is essential. Joints shall be so made that their current-carrying capacity is not less than that of the conduit itself. Slackness in joints may result in deterioration and even complete loss of continuity. Plain slip or pin-grip sockets are insufficient to ensure satisfactory electrical continuity of joints. In the case of screwed conduit, lock nuts should also be used.

12.3.6 *Pipes and Structural Steel Work* — Pipes, such as water pipe, gas pipe, or members of structural steel work shall not be used as earth-continuity conductor.

12.4 Earth Wires

12.4.1 Earth wires shall be protected against mechanical damage and possibility of corrosion particularly at the point of connection to earth electrode or earth-continuity conductor.

12.4.2 All earth wires shall have a cross-sectional area not less than about one-half of the largest conductor to be protected but in no case shall have a cross-sectional area less than 3·0 mm² if of copper and 6 mm² if of galvanized iron or steel.

12.4.3 The connection of the earth wire to the earth electrode or earth-continuity conductor shall be readily accessible and soundly made by the use of soldered joints or substantial clamps of non-ferrous material.

12.4.4 All joints shall be made on tinned surfaces.

12.5 Protection Against Earth Leakage

12.5.1 All metal work, such as window bars, shall be isolated in such a way that they cannot come in contact with any live part or earthed metal work.

12.5.2 It is recommended that lamp holders and lighting fittings should be so arranged that in normal operation no metal parts of lamp caps or lamp holders can be touched. This may be achieved either by all insulated construction of lighting fittings or by the provision of insulating shrouds for the lamp holders.

12.6 Bonding — The metal sheath and armour of cable, metal conduits and other earth-continuity conductors shall be kept electrically separate from the metal work of other services, and particularly from pipes carrying gases or flammable liquid where it is necessary to bond earth-continuity conductors or the metal enclosures of cables, conductors or other apparatus to specific non-electrical equipment like pipes, the latter shall be kept electrically separate from other non-electrical apparatus and the bonds shall be made at specified points.

12.7 Earthing in Lifts

12.7.1 Requirements of earthing in lifts shall generally conform to IS : 1860-1961*.

12.7.2 Frames of motor, winding machine, control panel, and cases and covers of tappet switch and similar electrical apparatus which normally carry the main current shall all be earthed. The cross-sectional area of the earth wire shall not be less than about one-half that of each current carrying conductor to be protected but in no case shall it be less than 3·0 mm^2 if of copper and 6 mm^2 if of galvanized iron or steel.

12.7.3 The exposed metal parts of electrical apparatus installed on a lift car shall be sufficiently bonded and earthed.

13. EARTHING OF DOMESTIC FITTINGS AND APPLIANCES

13.0 Earthing of domestic appliances arises in case they have only functional insulation. Appliances having reinforced or double insulation need not be earthed.

---

*Code of practice for installation, operation and maintenance of electric passenger and goods lifts.

13.1 Plugs and Sockets — All plugs and sockets shall be of three pin type, one of the pins being connected to earth.

13.2 Lighting Fittings — If the bracket type lamp holders are of metallic construction it is recommended that they should be earthed. All pedestal lamp fittings of metallic construction shall be earthed.

13.3 Fans and Regulators — Bodies of all table fans, pedestal fans, exhaust fans, etc shall be earthed by the use of three pin plugs. The covers of the regulators, if of metallic construction shall be earthed by means of a separate earth wire.

13.4 Cooking Ranges — Bodies of hot-plates, kettles, toasters, heaters, ovens, water boilers shall all be earthed by the use of three pin plugs. However, if fixed wiring has been used, then a separate earth wire shall be used for earthing these appliances.

13.5 Bath Room — The body of automatic electric water heaters shall be earthed by the use of a three pin plug or by a separate earth wire, if fixed wiring has been done. All non-electrical metal work including the bath tub, metal pipes, sinks and tanks shall be bonded together and earthed.

13.6 Radio Sets — From the point of view of good reception it is recommended that radio sets should be earthed through an electrode different from that of the main earth system for other electrical appliances. However, if it is not possible to have separate earth electrode, radio sets may be earthed through the main earth system.

13.7 Miscellaneous Apparatus — Where appliances utilizing gas and electricity are in use, for example gas-heated electrically-driven washing machines, the inlet end of the gas supply shall be either fitted with a strong insulating bush, substantial enough to stand a flash test of 3 500 V and so designed as to be difficult to detach, or, where it is desirable or necessary that metal work in proximity to electrical apparatus be bonded to the earthed metalwork of the latter, as for example, in kitchens, the gas supply shall be introduced through a non-conducting plastic pipe from a point not in proximity to earthed metalwork. Where separation is not easily achieved, for example, as in cases of direct-coupled motor-driven gas boosters and motorized gas valves, the metalwork of the electrical equipment shall be bonded to the metal or pipework of gas equipment. In such cases the addition to the motor control gear of a differential or current-balance type of circuit-breaker, designed to operate at low values of fault current, would afford a desirable safeguard against fault current transfer specially where the rating of the plant is of a size and capacity which entails correspondingly high ratings for the normal overload protective devices.

The refrigerators, air conditioners and coolers, electric radiators, electric irons, etc, shall all be earthed by the use of three pin plugs.

14. EARTHING IN INDUSTRIAL PREMISES

14.0 In factories and workshops all metal conduits, trunking, cable sheaths, switchgear, distribution fuse boards, starters, motors and all other parts made of metal shall be bonded together and connected to an efficient earth system. The electricity regulations made under the Factories Act require that adequate precautions shall be taken to prevent non-current-carrying metalwork of the installation from becoming electrically charged.

14.0.1 In larger installations, having one or more substations, it is recommended to parallel all earth continuity system.

14.1 Earth Electrodes — Any of the earth electrodes as mentioned in **7.1**, except cable sheath, may be used in industrial premises. They should satisfy the requirements of **6.1** also.

14.2 Earth Continuity Conductor

14.2.1 All earth continuity conductors shall have a cross-sectional area not less than about half that of the current-carrying conductor and in no case shall be less than 3·0 mm^2 if of copper and 6 mm^2 if of galvanized iron or steel. It need not have a cross-sectional area greater than 65 mm^2 of copper.

14.2.2 Conduits may be used as earth continuity conductors provided they are permanently and securely connected to the earth system. They shall also satisfy the requirements of **12.3.5**. However where by nature of the process metal conduits cannot be used as earth continuity conductor on account of corrosion, etc, tough rubber or PVC sheathed cables may be used in which case they shall incorporate an earth continuity conductor.

14.2.3 Flexible conduits shall not be used as earth continuity conductors. A separate earth wire shall be provided either inside or outside the flexible conduits which shall be connected by means of earth clips to the earth system at one end and to the equipment at the other end.

14.3 Earth Leakage Protection — Use of earth leakage protection shall be made where greater sensitivity than provided by overcurrent protection is necessary. With a good earth electrode, overload protective devices may be used as earth leakage protective device.

14.3.1 In addition to the advantage of sensitivity gained by such methods, the circuits may be relieved of the thermal and mechanical shocks associated with the clearance of heavy faults.

14.3.2 Some degree of discrimination may in certain cases be introduced with advantage by providing the delay in the operation of an earth-leakage trip, so that earth faults on smaller subsidiary circuits protected by fuses have time to clear and prevent the opening of the circuit-breaker, controlling a larger part of the installation.

14.4 Fire Protection — In parts of factories in which there is risk of fire or explosion due to the use of flammable materials, not only shall flame-proof apparatus be used, but particular attention shall be paid to the tightness of screwed conduit joints in order to ensure that under fault conditions no hot spot or arcing between lengths of conduit may lead to ignition with consequent fire or explosion.

14.5 Earthing of Portable Appliances and Tools

14.5.0 Portable appliances and tools having reinforced or double insulation need not be earthed.

14.5.1 Good electrical continuity between the body of a portable appliance and the earth continuity conductor shall always be maintained.

14.5.2 It shall be ascertained that the fixed wiring at the appliance inlet terminals has been done correctly and in accordance with IS : 732-1963*.

14.5.3 A single pole switch shall not be connected in the earth conductor.

14.5.4 Only three pin plugs shall be used. The plugs shall satisfy the requirements of relevant Indian Standard.

14.5.5 No twisted or taped joints shall be used in earth wires.

14.5.6 Additional security may be obtained by arranging the earth continuity conductor in the flexible cable between the socket outlet and the portable appliance in the form of a loop through which a light circulating current provided by a small low-voltage transformer is passed when the appliance is in use. Any discontinuity in this loop will interrupt the circulating current and can thus be caused to operate a relay and disconnect the supply from the portable appliance (*see* Fig. 11).

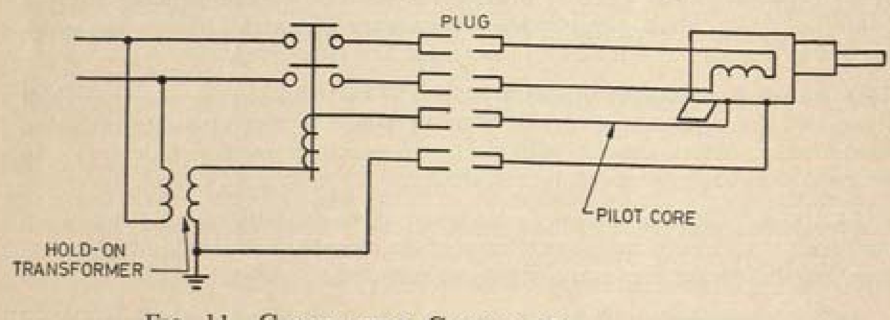


Fig. 11 Circulating Current Protection for Portable Apparatus

*Code of practice for electrical wiring installations (system voltage not exceeding 650 volts) (*revised*).

15. EARTHING OF MISCELLANEOUS APPARATUS

15.1 Earthing of Electrically Driven Machine Tools

15.1.0 Earthing of electrically driven machine tools shall be done generally in accordance with **8** of IS : 1356-1964*.

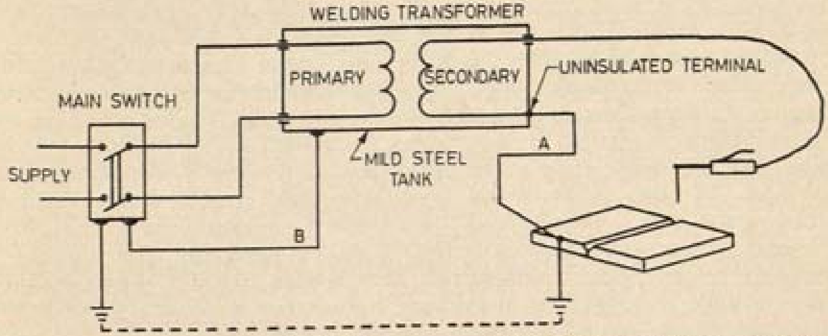
15.1.1 Irrespective of the size or type of machine tool, the bed plate of the machine shall be earthed by means of a strip or conductor of not less than 6·5 mm² cross-sectional area if of copper and 16 mm² if of galvanized iron or steel. The strip or conductor shall be securely fastened to the bed plate by means of a bolt.

15.2 Earthing of Electric Arc Welding Equipment

15.2.1 All components shall be effectively bonded and connected to earth. The transformers and separate regulators forming multi-operator sets and capacitors for power factor correction, if used, shall be included in the bonding.

15.2.2 All terminals on the output side of a motor generator set shall be insulated from the carcase and control panel, as the generator is not connected electrically to a motor and therefore the welding circuit is electrically separate from the supply circuit including the earth.

15.2.3 In case of transformer sets, which for welding purpose are double wound, an 'earth and work' terminal shall be provided. In single-phase sets this terminal shall be connected to one end of the secondary winding (*see* Fig. 12) and in case of three-phase sets this shall be connected to the neutral point of the secondary winding.



NOTE — If the return cable 'A' is not connected to the workpiece, welding current will return via cable 'B'.

FIG. 12 EARTH AND WORK CONNECTION FOR WELDING

*General requirements for electrical equipment of machine tools (*revised*).

15.3 Earthing of Industrial Electronic Apparatus

15.3.0 The earthing of these apparatus shall follow normal practice but attention shall be paid to the points discussed in **15.3.1** to **15.3.5**.

15.3.1 Any industrial electronic apparatus which derives its supply from two pin plugs incorporates small capacitors connected between the supply and the metal case of the instrument to cut down interference. This capacitor shall be securely earthed.

15.3.2 When an oscilloscope is being used to examine the wave-form of a high frequency source, the oscilloscope shall be earthed by a conductor entirely separate from that used by the source of high frequency power. However, when an oscilloscope is being used on a circuit where the negative is above earth potential and also connected to its metallic case, the earthing of the oscilloscope is not possible. Precautions shall be taken that in such a case the oscilloscope is suitably protected from other apparatus.

15.3.3 High frequency induction heating apparatus shall be earthed by means of separate earth wire by as direct a route as possible.

15.3.4 Dielectric loss heating equipment work at frequencies between 10 Mc/s to 60 Mc/s according to its use. These should not be directly earthed. At 30 Mc/s for example, a quarter wave-length is nearly 250 cm and an earth wire of this length or odd multiples of it is capable of being at earth potential at one end but several hundred volts at the other end. This is due to the presence of standing waves on the earth conductor which besides being dangerous can result in energy being radiated to the detriment of communication services. In such a case it is recommended to mount the equipment on a large sheet of copper or copper gauze, the earth conductor being connected to it at several points.

15.3.5 In cases where direct earthing may prove harmful rather than provide safety, for example, high frequency and mains frequency coreless induction furnaces, special precautions are necessary. The metal of the furnace charge is earthed by electrodes connected at the bottom of the charge, and the furnace coils are connected to the mains supply but are unearthed. A relay is connected by a detection circuit which itself is earthed to the coils. The object is to prevent dangerous break through of hot metal through the furnace lining, the earth detection circuit giving a continuous review of the conditions for the furnace lining. When leakage current attains a certain set maximum it becomes necessary to take the furnace out of service and to re-line (*see also* **4.2.1**).

15.4 Earthing of Electro Medical Apparatus

15.4.0 The earthing of these apparatus shall follow normal practice. However, since in many cases the apparatus is connected to a patient's body by means of electrodes having a very low contact resistance, special care has to be taken in design and installation of these apparatus.

15.4.1 *Biological Amplifiers* — All apparatus like electrocardiographs, electroencephalographs and electromyographs shall be connected to a good low resistance earth. Unless a good earth is used, it is likely that spurious signals from the supply mains may be injected into the amplifier.

15.4.2 *Surgical Diathermy and Therapeutic Diathermy Apparatus* — The chassis of all such apparatus shall be connected to a good earth. To avoid radio-frequency interference from being fed into the mains these apparatus may incorporate a filter, fitted with capacitors between the mains leads and earth. If these filter capacitors are of too large value, any defect in the earth connection of the chassis may result in dangerous shocks.

15.4.2.1 In the use of these apparatus a radio-frequency current is passed from a live electrode of small area through the patient's body to an 'indifferent' electrode of large area. This 'indifferent' electrode is normally earthed, thus bringing the patient to earth potential. When radio-frequency current is passed through the patient, the only point which is really at earth potential is the 'indifferent' electrode. If any person or object which is at earth potential or has appreciable capacitance to earth touches the patient, some of the current will be diverted through the new path to earth resulting in burning of either or both the patient and the person touching the patient.

15.4.3 *Cautery-Light Units* — These apparatus are used in operation theatres to supply endoscopic lamps which are introduced into body cavities. Usually these instruments are basically transformers having low voltage secondary. In these instruments 'earth free' circuit shall be used. Therefore the insulation between primary and secondary winding should be extremely reliable. It is recommended to interpose an earthed screen between the primary and secondary windings.

15.4.4 *X-Ray Apparatus* — The metallic shield in which the tube is enclosed shall be connected to earth to avoid the potential of the shield rising and thus protect both the operator and the patient from possible contact with voltages of the order of 100 kV.

16. MAINTENANCE OF EARTH ELECTRODES AT CONSUMER'S PREMISES

16.1 It is recommended that periodical check tests of all earth electrodes should be carried out. If possible, records should be maintained.

16.2 Where earth-leakage circuit-breakers are employed, a check shall be kept on the associated earth-electrode by periodically operating the testing device which is embodied in the earth-leakage circuit-breaker.

16.3 The neighbouring soil to the earth electrode shall be kept moist, where necessary, by periodically pouring water through a pipe where fitted alongwith it or by pouring water in the immediate vicinity of the earth electrode.

SECTION 3 SUBSTATIONS, GENERATING STATIONS AND OVERHEAD POWER LINES

17. EARTHING AT SUBSTATIONS AND GENERATING STATIONS

17.1 General Requirements

17.1.1 In substations and generating stations there shall be provisions for earthing the following:

a) The neutral points of each separate system which have to be earthed at the station. The various systems concerned may be at different voltages;

b) Apparatus, framework and other non-current-carrying metal work associated with each system, for example, transformer tanks, switchgear frames, etc; and

c) Extraneous metal framework not associated with the power system, for example, boundary fence, steel structure sheaths of communication cables, etc.

17.1.2 The neutral points of systems of different voltages, all apparatus and framework and other non-current-carrying metal work may all be connected to one earthing system.

17.1.3 However, if design considerations necessitate complete separation between systems at different voltages, separate earth electrodes shall be used for the neutral point of each supply system to be earthed at the site and for the extraneous metal work at each station and each system at a given site shall be isolated from the others and from extraneous metal work to withstand the maximum voltage which can be developed across any earth electrode at that site.

17.1.4 From the point of view of safety to personnel, the aim shall be to ensure that in both normal and abnormal conditions no dangerous voltages appear on the apparatus to which a man has legitimate access.

NOTE — In this respect 'earthed' is essentially a relative term. Particularly with the high voltage systems having directly earthed neutrals it is not practicable to ensure that during fault conditions all metal parts normally earthed are at the true earth potential. Therefore the aim shall be to ensure that there is an effective connection of very low impedance and adequate current-carrying capacity between the parts with which one may be in simultaneous contact. At the same time it is recommended to arrange that as far as possible large fault currents do not flow between such parts.

17.1.5 From the point of view of the possible damage to apparatus during fault conditions, it shall be ensured that the lowest practicable voltage appears between the earthed parts of station equipment and the main body of earth, so that insulation breakdown or burning does not occur on apparatus connected to points outside the substation (for example, apparatus connected to pilot or telephone cables, cable sheaths, etc). For similar reasons the voltage drop between earthed points in the station shall also be kept to a minimum. In addition, the effectiveness of any surge protection provided depends in part on the adequacy of the connection of the protective devices to earth. In this case the high instantaneous currents, often containing high frequency components, require that the earth connection shall not only be of low resistance but of low reactance, that is, as short and as free from changes of direction as practicable.

17.1.6 When two or more neutrals are connected to the common earth bus, in case of a short-circuit all the neutrals will be raised above absolute earth potential to a potential which equals the product of the current and the resistance of the earth bus to absolute earth. In case one of the neutrals is that of a high voltage system, for example 11 kV, the whole system may thereby be raised to a comparatively high potential above the earth established at another station on the low-voltage system. In some cases this potential may be high enough to endanger apparatus on the low-voltage system and even to endanger life. On the other hand if the low-voltage neutral is not connected to the common earth system but has a separate earth bus, then there will be a difference of potential between the high-voltage and low-voltage neutrals, and there may exist a dangerous potential gradient across the earth surface which would endanger life. In most cases with a low-resistance earth bus and the neutrals connected to a common earth system, there will be no danger to the low-voltage system and the advantage in keeping everything in the station at a common potential above earth will outweigh the disadvantages. Extreme and unusual cases, however, may require special investigation.

17.1.7 The disturbances transmitted from one electrical system to the other under fault conditions are not excessive if the resistances of earth electrodes are small compared with the total impedances which limit earth-fault currents. In high-voltage systems at voltages of 66 kV and below, if earth-fault currents are not suitably limited by the normal impedance of the supply it shall be achieved by the insertion of resistors between the system neutral and earth electrode*. Such resistors are not normally necessary for this purpose† on systems of voltages above 66 kV where the system at the next stage of transformation can usually withstand under fault conditions a temporary excess voltage of the order of the product of the

*The connection between neutral and any such resistor should be adequately insulated from earth.

†Neutral resistors may, however, be necessary for other reasons, for example, to ensure stability of the system.

higher voltage fault current and the earth electrode resistance although when the transformation ratio is large the electrode resistance should be kept low.

17.1.8 As an alternative to resistors for the above purpose, arc-suppression coils may be used except on systems of very high voltage. Furthermore, special attention should be paid to the long time fault-current capacity of earth electrodes used on systems protected by arc-suppression coils (*see* **6.2**). Provision may be made for the automatic short-circuiting of arc-suppression coils after a stipulated period of fault.

17.1.9 The earthing system shall be mechanically robust and joints shall be capable of retaining low resistance even after many passages of fault current.

17.1.10 Joints shall be either riveted, bolted, brazed or welded. Where the diameter of the bolt exceeds one quarter of the width of the earth bar, the connection to the bolt shall be made with a wider piece or flag of copper jointed to the earth bar (*see* Fig. 13). The design of joints shall be based on a maximum allowable temperature-rise, which in the case of bolted joints should be limited to 250°C and for brazed joints to 450°C.

17.1.11 Main earth bars shall be spaced sufficiently from the surface on which they are fixed such as wall or trenches to allow for the connections to be made easily. Where a portable apparatus is to be earthed a suitable loop attached to the earth bar shall be provided to accept the earthing clamp.

17.2 Earth Electrodes

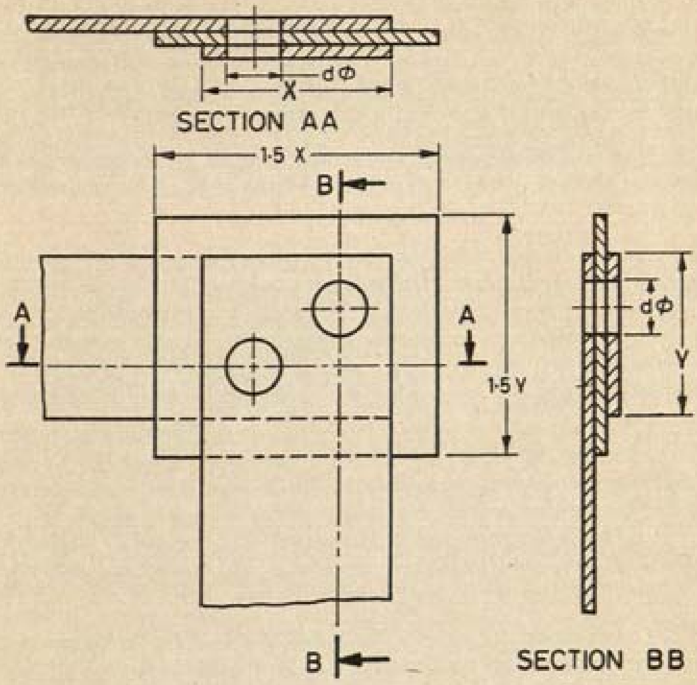
17.2.1 The earth electrode shall have low resistance, depending on the system voltage and fault current envisaged, under all climatic conditions.

17.2.2 The rise in potential between the earth system and the general body of the earth shall be kept as low as possible.

17.2.3 The earth electrode shall be capable of carrying such currents as may arise in normal operation and during fault and surge conditions without undue increase in resistance.

17.2.4 The electrodes shall be so placed that all lightning protective earths may be brought to the earth electrode by as short and straight a path as possible to minimize surge impedance.

17.2.5 If the prospective fault current is high (more than 6 kA), plate electrodes may be used in which case it shall not be less than 1·2 m × 1·2 m in size and of 12·5 mm thick if made of iron or steel or 6 mm thick if made of copper (*see also* **17.2.8**).



NOTE — Bolt diameter exceeding one-fourth the width of smaller strip.

FIG. 13 CONNECTION OF EARTH STRIPS WITH BOLTS

17.2.6 As an alternative to plates, in the above conditions, cast iron pipes, not less than 100 mm in diameter, 3 m long and not less than 12 mm thick, may be used.

17.2.7 As a further alternative to **17.2.5** and **17.2.6**, mild steel pipes, not less than 35 mm in diameter, may be used.

17.2.8 If the fault current is envisaged to be low and the soil resistivity is high it is recommended to make use of rod earth electrodes. In regions of high soil resistivity where fault currents are envisaged to be high, earthing mat or bare strip or round conductor in conjunction with other electrodes may be used. These forms of electrodes have particular advantage where rock is at or near the surface of the area including or surrounding the station and may also be employed over a limited area as an 'earth mat' where it is particularly desirable to ensure absolute protection to a man standing at a certain spot, for example, at places where isolators and switches are to be operated manually.

17.2.9 If a very low resistance is required it is recommended to treat the soil in accordance with **5.3.7** (*see also* **17.2.11**). This treatment, however, shall have to be repeated frequently depending upon soil conditions. For clay and loam the frequency may be of the order of 8 to 10 years and for sandy and porous soil it may be of the order of 2 years.

17.2.10 The size of the earthing electrode shall be in accordance with **7** and its resistance shall be calculated according to **8**. The resistance of each earth system shall not be more than 1·0 ohm.

17.2.11 *Salt Treatment* — In the case of pipe electrodes it is recommended to perforate these and to treat the soil by pouring salt solution down them. In the case of electrodes installed in a trench it is recommended to use salt as a top dressing left to percolate through the soil with the surface moisture. If it is required to excavate the soil before installing an electrode, it is recommended to mix the excavated soil with salt before refilling.

17.2.11.1 Although substantial reduction of earth resistance can be effected by the use of coke around the earth electrode for a distance of 25 cm, this method is not recommended as it results in rapid corrosion not only of the electrode but also of cable sheaths, water pipes or steel frame work, etc, to which it is bonded. However, if coke treated electrodes are used, they shall not be situated within 6 m of other metal work which may be affected by it unless the latter is suitably protected.

17.2.12 *Location and Number of Earth Electrodes* — As far as possible earth electrodes for generating stations and indoor substations shall be installed adjacent to the building and for outdoor substations within and adjacent to the perimeter fence. At large sites, apart from securing a sufficiently low resistance and adequate current-carrying capacity a reasonable distribution of electrodes is also necessary. A general guidance regarding the number of earth electrodes required may be had from Fig. 14.

17.2.13 *Voltage Gradient Around Earth Electrodes* — Voltage gradients around earth electrodes under fault conditions may reach such values as to damage telephone and pilot cables in the vicinity. The area over which such injurious voltages may occur is dependent on whether the feeders are mainly overhead lines or buried cable. In the former case approximately 50 percent of the voltage drop from the electrode occurs within a distance from the centre of the station equal to half the maximum diagonal of the boundary fence, and 75 percent of the voltage drop occurs within twice this distance. The effect of buried power cables in the vicinity of the station is virtually to extend the area of the electrode system and thus to increase the distance at which a given proportion of the electrode potential exists. This effect is dependent upon the resistance to earth of the cable covering. It is recommended that steps should be taken to protect any pilot or light-current carrying lines within the area over which a dangerous voltage may be expected to exist, either by applying suitable sheath insulation to such

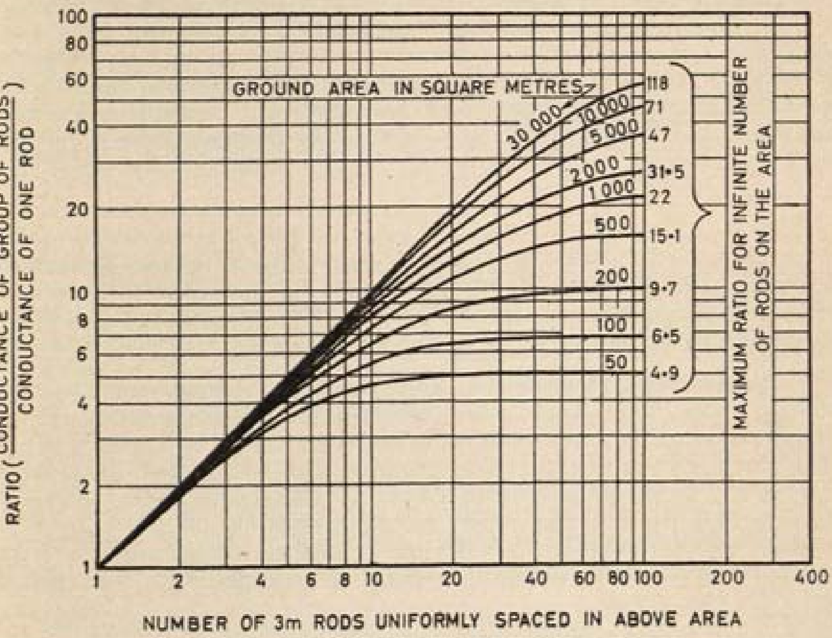


FIG. 14 APPROXIMATE NUMBER OF ROD EARTH ELECTRODES REQUIRED IN A GIVEN AREA

lines where they are in cable or by running them overhead within the danger area.

An alternative solution for stations where both the feeders and the pilot cables are buried, is to run the latter in a line as far removed as possible from the route of the power cables.

NOTE — Precautions which should be taken in connection with pole-mounted transformers to avoid danger to animals from voltage gradients are dealt within **6.3**.

17.3 Earth Continuity Conductors

17.3.1 *Disposition* — It is necessary to provide permanent and substantial connections between all likely sources of fault current and the earth electrodes so as to afford a low-resistance path for fault currents both to earth and between items of equipment. In addition all other metal parts in or about the station should be connected into the main station earthing system. The most efficient disposition of earthing conductors required will depend on the layout of apparatus and the following may be taken as a guide.

17.3.1.1 *Indoor apparatus* — A main earth bus shall be provided and connected to the framework of each item and to the earth electrodes. For all installations there should be a connection to the earthing ring at each end of the earth bar, or if this is in the form of a ring, at several points on the earthing ring. Where the structure of a switch board is extensive or occupies more than one floor, a further parallel earthing ring shall be required which shall be connected to the main earthing ring at least at two points.

The main earth bar should be so placed that cable sheaths may be readily connected to it. It should be accessible for the connection of any detachable earthing devices provided with the switchgear. Branch connections from the main earth bar should be provided to all ancillary apparatus such as control and relay panels, constructional steel work, fire extinguishing apparatus, etc.

Where bus-bar protection is effected at switchboards by frame leakage, two main earth wires are required. The frame earth wire interconnecting the framework of the switch units will be connected to the true earth wire through a current transformer and bolted links for test purposes. The true earth wire should be run separately from the frame earth wire in convenient position for the connection of cable sheaths and earthing devices. Where it is mounted on the switch units it should be insulated therefrom by insulation capable of withstanding a test voltage of 4 kV for one minute.

17.3.1.2 *Outdoor stations* — A main earthing ring shall be provided round the stations and shall be so disposed as to allow the shortest subsidiary connections to all major apparatus such as transformers and circuit-breakers. The main earthing ring shall be connected to all earth electrodes. For larger stations the ring should be reinforced by one or more cross connections. From the main earth bus, branch connection shall be taken to each apparatus, and where several items of an apparatus lie together, a subsidiary ring with short branches is recommended to a number of longer individual branches from the main earth bus. The aim should be to provide closed loops or a mesh system as far as possible.

Isolator and earthing-switch operating mechanisms and circuit-breaker control kiosks not integral with the circuit-breakers should be connected to the earth system by a branch entirely separate from that employed for earthing the isolator or earthing-switch bays or the circuit-breaker structure so that a short definite connection exists between the hands and feet of any operator and this connection is not likely to carry fault current.

Where the earth wire of an incoming line ends at the terminal supports and is not connected to a point on the substation structures, a subsidiary earth connection shall be provided between the substation earth system and the base of the support. If the latter lies outside the substation fence, the earth connection shall be buried where it passes under the fence and shall be kept well clear of the latter.

Where earthing switches are mounted on steel or reinforced concrete structures, the structure shall not be relied upon to provide the earth connection from them to the system. A separate connection shall be provided.

Earth connections to surge diverters shall be of ample cross-section and as direct as possible. They shall not pass through iron pipes which would increase the impedance to surges of the connection. The earth connections of the diverters shall be interconnected with the main earthing system since for the effective protection of the substation equipment, a definite connection of low impedance between the equipment and the diverters is essential.

17.3.2 *Size* — The size of earthing conductor required is determined by consideration of voltage drop and temperature-rise. It is recommended that under fault conditions the voltage drop between two normally earthed parts with which any one is likely to be in simultaneous contact should not exceed 32 volts. The voltage drop is not, however, always readily calculable, but the size of connection required for thermal consideration will in general be sufficient to keep these voltage drops within safe limits.

The thermal rating of earth connections shall be based on the short-time current rating of the associated switchgear and a maximum temperature which will not cause damage to the earth connections or to apparatus with which they may be in contact.

The size of earth bus and earth continuity conductor is determined by the amount of current flow and its duration, based on a maximum allowable temperature-rise, which in the case of sweated and riveted joints is limited to 250°C and for brazed joints to 450°C.

17.3.2.1 The following equation has been derived for determining the size of the earth bus and conductors:

a) For sweated and riveted joints

$$A = 0{\cdot}005\,4\ I\sqrt{t}$$

b) For brazed joints

$$A = 0{\cdot}004\,4\ I\sqrt{t}$$

where

A = cross-sectional area in mm^2,

I = amount of current flow in amperes, and

t = duration of current flow in seconds.

17.3.2.2 It is recommended that the duration of the earth fault current should be taken as 30 seconds. This will give area of cross-section of the main earth bus as follows:

$A = 0{\cdot}029\,6\ I\ \text{mm}^2$ for sweated, riveted and bolted joints; and

$A = 0{\cdot}024\,1\ I\ \text{mm}^2$ for brazed joints.

17.3.2.3 The above apply only for copper earth bus and earth continuity conductor. For galvanized iron or steel earth bus and earth continuity conductor, the size may be calculated on the basis of equivalent current-carrying capacity.

17.3.2.4 The above applies to connections which are in any way likely to carry the whole or a substantial part of the fault current. Connection to apparatus not associated with the primary equipment and which are not to carry fault current may be of lesser cross-section but for practical reasons a minimum size of 65 mm² with a minimum thickness of 1·6 mm for copper and 200 mm² with a minimum thickness of 3 mm for galvanized iron and steel is recommended.

17.3.2.5 It is the general practice for the main earth bar to be of somewhat heavier cross-section than the minimum necessary to carry the fault current, so that the voltage drop over the station as a whole is kept as low as possible. For example, in indoor distribution station with fault currents not exceeding 22 kA a minimum size of 120 mm² copper may be used and for outdoor stations for 33 kV and upwards where long runs may be required a minimum size of 180 mm² copper is recommended. The corresponding galvanized iron and steel sizes may be calculated on the basis of equivalent current carrying capacity.

17.3.2.6 Where the system neutral is earthed through a resistance or an arc-suppression coil, it should be noted that the restriction of fault current provided by these devices does not apply for every type of fault. In selecting the size of earth connection, therefore, it is recommended that no differentiation be made between such systems and those having a solidly earthed neutral.

17.3.3 *Construction* — It is essential for the safety of personnel and plant that an earth system shall remain effective throughout the life of the plant. It is difficult in many cases to make a check of continuity after installation. The system shall, therefore, be mechanically robust and protected from corrosion where necessary. All joints shall be capable of retaining low resistance after many passages of fault current.

17.3.3.1 *Joints* — In view of the maximum temperatures allowed, joints shall be either riveted, sweated, brazed, bolted or welded. For rust protection the welds should be treated with barium chromate. Welded surfaces should be painted with red lead and aluminium paint in turn and afterwards coated with bitumen. Joints in the earth bar between the switchgear units or to cable sheaths which may require subsequently to be broken should be bolted and the joint faces tinned.

17.3.3.2 *Terminations* — Where the diameter of the bolt for connecting the earth wire (or strip) to apparatus exceeds one quarter of the width of the earth wire (or strip) the connection to the bolt shall be made with a wider piece or flag connected to the earth wire (or strip). Earth wires (or strips) and flags shall be tinned at the point of connection to equipment and special care is required to ensure a permanent low-resistance contact to iron or steel (*see* Fig. 13).

17.3.3.3 *Fixing* — Main earth continuity conductors shall be spaced sufficiently from the surface to which they are fixed, such as walls or the side of trenches, to allow for making permanent or temporary connections. Where the earth continuity conductor itself is drilled for fastenings, the diameter of the hole shall not exceed one quarter of the width of the strip. Copper earth bars shall not be fixed by ferrous screws or fittings. Where portable apparatus are in use, suitable loops attached to the earth continuity conductor to accept the earth clamps shall be provided.

17.3.3.4 *Protection from corrosion* — Iron, lead and zinc are all anodic to copper whose presence, therefore, promotes their corrosion where rain-water or soil water contains electrolytes. Connections between copper and galvanized equipment should, therefore, be made on a vertical face and protected with paint or grease; galvanized fixing clamps shall not be used for earth bars. Earth bars leading to cast-iron electrodes shall be served for protection in the vicinity of the latter and the bonds to the electrodes shall be protected by a thick layer of compound. Where there is evidence that the soil is aggressive to copper, buried earthing conductors shall be protected by suitable serving or sheath.

17.3.4 *Connections to Separate Earth Electrodes* — Where it is necessary to connect items of apparatus to earth electrodes which are insulated from and outside the resistance area of the main station earth electrodes, the earthing conductors for this purpose shall be suitably insulated from those of the main station earthing system to withstand the voltage rise which may occur in the latter under fault conditions. This may be effected by using insulated cables or, where the earthing conductors are not buried, by suitable spacing and support. In the latter case the separation within the station area should be such that at no point it is possible for a person to make simultaneous contact with any parts of two separate earthing systems.

17.3.5 Earthing through steel structure should not be permitted if it has bolted or riveted joints. It may be permitted if the joints are welded or where permanent electrical continuity can be ensured.

17.4 Neutral Earthing

17.4.1 It is recommended to use one of the following methods for earthing of generator and transformer neutrals:

a) Solid earthing,

b) Resistance earthing,

c) Reactance earthing, and

d) Arc-suppression coil earthing.

17.4.1.1 The selection and the type of earthing to a certain extent depends on the size of the unit and the system voltage and also protection scheme which is to be used. General guide on the selection of type of earthing is explained in **17.4.2** to **17.4.5**.

17.4.2 *Solid Earthing* — A direct metallic connection shall be made from the system neutral to the main earthing ring. It is recommended to use this method when the maximum earth fault current is not likely to cause damage to plant, cables and lines and loss of stability of system.

17.4.3 *Resistance Earthing* — Resistance earthing is generally used when the fault current is likely to be so high as to cause damage to generators or transformers. The resistors shall comprise of metallic resistance units supported on insulators in a metal frame or shall be a liquid resistor of a weak aqueous solution either of zinc chloride or sodium carbonate. Metallic resistors have a constant resistance which does not change with time while liquid resistors have to be treated frequently specially after the clearance of a fault. Metallic resistors are slightly inductive and this is a disadvantage with overhead lines, since travelling waves and impulses are subject to positive reflection and this is likely to unduly stress the insulation of the equipment and cause breakdown. Use of liquid resistors is recommended only at voltages above 6·6 kV. All neutral earthing resistances should be designed to carry their rated current for a short period, usually 30 seconds.

17.4.4 *Reactance Earthing* — When the zero sequence reactance of generators or transformers is so low as to cause excessive fault current, usually reactance earthing is used. A single phase reactor is inserted between the neutral and the earth to limit fault current. Care shall be taken to see that dangerously high transient voltage during system fault or switching operations do not occur due to high value of reactance of the earthing reactor.

17.4.5 *Arc-Suppression Coil Earthing* — In high voltage systems with isolated neutrals overvoltages caused by switching surges or by lightning may cause a line to flashover to earth. Considerable current will be drawn through the arc to charge the system capacitance to earth. The arc is quenched at zero voltage but may restrike at a higher voltage. This successive restriking of the arc often causes very high voltages to be built upon the transmission lines, and is known as 'arcing grounds'. To avoid isolation of system under earth fault conditions, arc-suppression coils are sometimes used, as shown in Fig. 15. Arc-suppression coil, also known as Peterson coil, is a tuned earthing reactor. It is tuned to the system capacitance in such a way as to make the reactance of the zero sequence network practically infinite, so that no fault current flows to the earth and there is no tendency for arcing grounds to occur. With the use of Peterson coil, arc current is reduced to such a small value that it is usually self-extinguishing, which increases continuity in service.

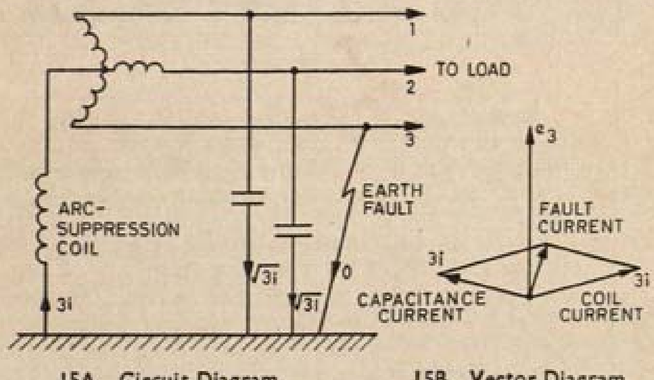


FIG. 15 SYSTEM EARTHING THROUGH AN ARC-SUPPRESSION COIL WITH AN EARTH FAULT ON ONE PHASE

17.5 General Earthing Arrangements at Substations

17.5.0 A typical earthing arrangement for an outdoor substation is shown in Fig. 16.

17.5.1 *Substations Giving No External Low-Voltage Supply* — Common earth electrodes should be used for both system earths and equipment earths. The items which need to be earthed separately from the main station earth electrode are the perimeter fence which are 2 m away from the earth bus and any coupling capacitors associated with carrier current equipment.

17.5.2 *Substations Giving an External Low-Voltage Supply (Excluding Pole-Mounted Transformers)* — The low-voltage system neutral should be connected to the station earth system. The electrode resistance shall be sufficiently low to avoid, as far as possible, the risk that an earth fault on the high-voltage system may cause a voltage rise of the neutral of the low-voltage system and consequent damage on that system (*see also* **17.1.7**).

17.5.2.1 Low-voltage cables from a substation fed by high-voltage overhead lines shall be insulated within the resistance area of the substation earth electrode unless it has been assured that there is no risk of dangerous rise of potential.

17.5.3 *Pole-Mounted Transformers* — In the case of pole-mounted transformers on overhead line systems difficulties may arise in areas of high soil

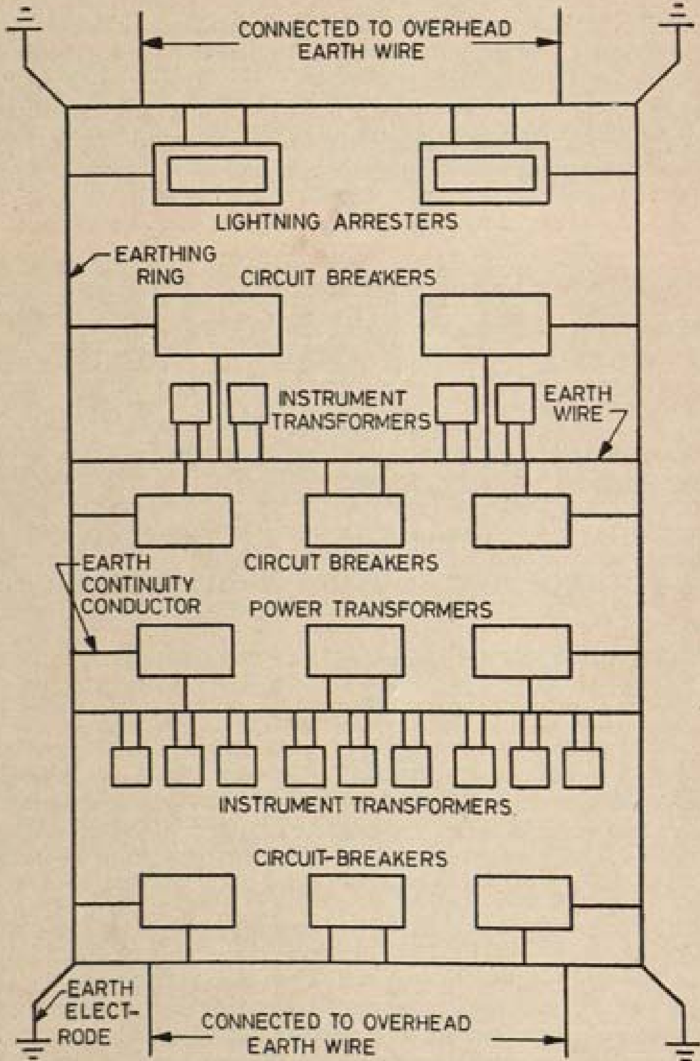


Fig. 16 A Typical Earthing Arrangement for an Outdoor Substation

resistivity. Here, if the pole also carries isolating switchgear with low-level operating handle, up to three separately earthed electrode systems may be required:

a) For the neutral of the low-voltage system. It is usually provided at a pole one span away on the low-voltage line;

b) For the high-voltage metal work (transformer tank, switch framework, support metal work). It consists of one earth electrode at or near the pole; and

c) In addition, an earth mat shall be provided, near the ground surface, in the position taken up by a person operating the switch handle; this mat shall be connected to the switch handle. The mat shall be electrically separated from the main electrode; this is achieved by spacing the nearest element of that electrode at least one metre from the periphery of the mat and by placing the two earth wires on opposite side of the pole.

17.5.4 *Substation Giving an External High-Voltage Supply* — Here also it is recommended to have common earth bus for both high-voltage and low-voltage systems. Where there are manual operating levers for high-voltage switchgear it is recommended to connect the operating handle to the system earth electrode.

To remove any voltage gradient that may exist between the operating lever and the ground on which the operator stands, a metal grid should be placed just below ground level and shall be connected to the system earth electrode.

17.5.5 *Earthing of Carrier-Current Equipment* — A separate earth electrode, generally a driven rod or pipe, should be provided immediately adjacent to the structure supporting the coupling capacitors. The earth connection thereto should be as short and free from changes of direction as possible. This earth shall be used only for the high frequency equipment. The structure supporting the coupling capacitors shall be earthed in normal way.

17.5.6 *Earthing of Cables* — Metal pipes or conduits in which the cables have been installed should be efficiently bonded and earthed. At specified points on the route where the presence of stray currents is suspected, the joints, the metal sheath and armour, if any, of the cables shall be bonded to the earthing system and connected to one or more earth electrodes. The cross-sectional area of every bond shall be not less than 65 mm^2 and in any case shall be such that the resistance of each bond connection shall not exceed the combined resistance of an equal length of metal sheath and armour, if any, of the cable.

17.5.6.1 *Bonding single-core cables in trefoil formation* — The method of bonding the metal sheaths of single-core cables in close trefoil formation shall preferably consist of sheet lead 3 mm in thickness and approximately 10 cm wide, wrapped round the trefoil cable assembly in such a manner as to make close contact therewith. The edges of the lead strip shall be bell-mouthed so as to improve the wiped connection which shall be made at each side. Free ends of lead shall be left so that connection can be made thereto by means of tinned copper strip between the lead ends and two outer copper backing strips. Three 8 or 10 mm galvanized steel or phosphor bronze bolts shall be used for the connection of the copper strip to the lead bond.

When buried direct in the ground, the complete bond shall be enclosed in a creosoted wood box which shall be filled in solid with bituminous compound.

17.6 Earthing of Transformers

17.6.1 *Generator Transformers* — Generator transformers connect the main transmission system, which generally operates at 132 kV or 220 kV, to the generators. It is recommended that neutral points of these transformers be directly earthed, thus permitting the grading of insulation in the transformer from the terminal end to the neutral point.

17.6.2 *Substation Transformers* — These transformers connect the sub-transmission system, which generally operates at 6·6 kV, 11 kV, 33 kV and 66 kV to the main transmission system. Where the fault current is expected to be too high, resistance earthing may be used to limit the fault current.

17.6.3 *Distribution Transformers* — These transformers connect the sub-transmission system to the distribution system and are generally connected delta on the higher voltage side and star on the lower voltage side. The neutral point should be connected directly to the earth.

17.6.4 *Transformers with Delta Windings* — It is sometimes necessary to earth a high-voltage system supplied from a transformer with delta windings. In such a case, an earthing transformer may be used as shown in Fig. 17. This provides a star point which may be earthed either directly or through a resistance, if desired.

17.7 General Earthing Arrangements at Generating Stations

17.7.0 A typical earthing arrangement for a generating station is shown in Fig. 18.

17.7.1 It is normal practice to earth the neutral points of three-phase high-voltage generators. Although the value of neutral earthing impedance is not critical it should be kept within certain limits to ensure satisfactory operation. Three methods are recommended for the earthing of generator neutral:

a) direct earthing,

b) resistance earthing, and

c) reactance earthing.

17.7.2 *Earthing of a Single Generator*

17.7.2.1 When the fault current of the generator is not expected to be too high, it may be earthed without any impedance in the circuit. In such a case it shall be ensured that the impedance between neutral and earth is so low that if an earth fault occurs on one phase of the system, sufficient current will flow to operate the protective devices.

17.7.2.2 If a resistance has been inserted between the neutral and the earth, quick acting protective devices shall be used so that on the occurrence of a fault the generator and its field shall automatically be disconnected. The earth resistance shall be of such a value that if a fault occurs outside the generator, the fault current will be restricted to the rated full load, current of the generator. The earth resistance, however, shall not be too low, for on the occurrence of an earth fault, the generator will be subjected to shock due to the load resulting from power loss in the resistor.

17.7.2.3 Reactance earthing is used to limit the fault current to a maximum of three-phase short-circuit current. In reactance earthing the current due to an earth fault on one phase is limited so as to minimize danger of serious damage to the stator and also that the generator could, if essential, remain in service until operational conditions permit its withdrawal.

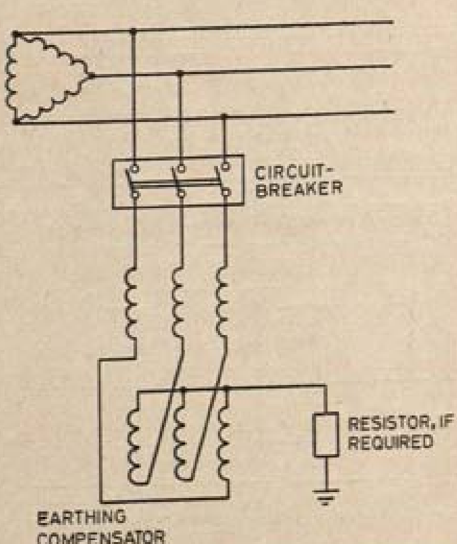


Fig. 17 Neutral Earthing Compensator

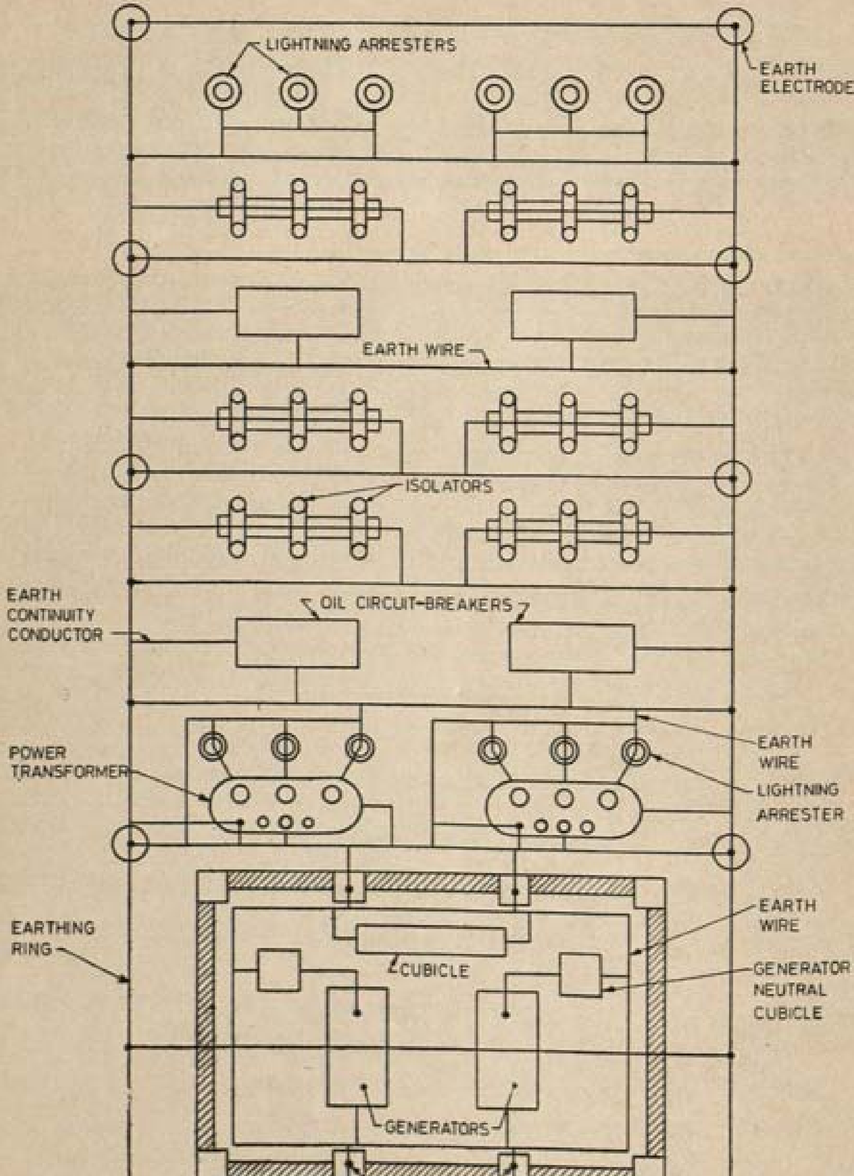


Fig. 18 A Typical Earthing Arrangement for a Generating Station

17.7.3 *Earthing of Generators in Parallel* — When more than one generator are operating in parallel, all the generator neutrals shall be earthed through an isolating switch (*see* Fig. 19). At any time when more than one generator is in service, only one earth isolating switch shall be kept on. This is necessary because, if too many neutral points are earthed either directly or through individual impedances, the fault current may become too high so that when earth fault occurs anywhere on the system there will be unnecessary damage to and disturbance in the system.

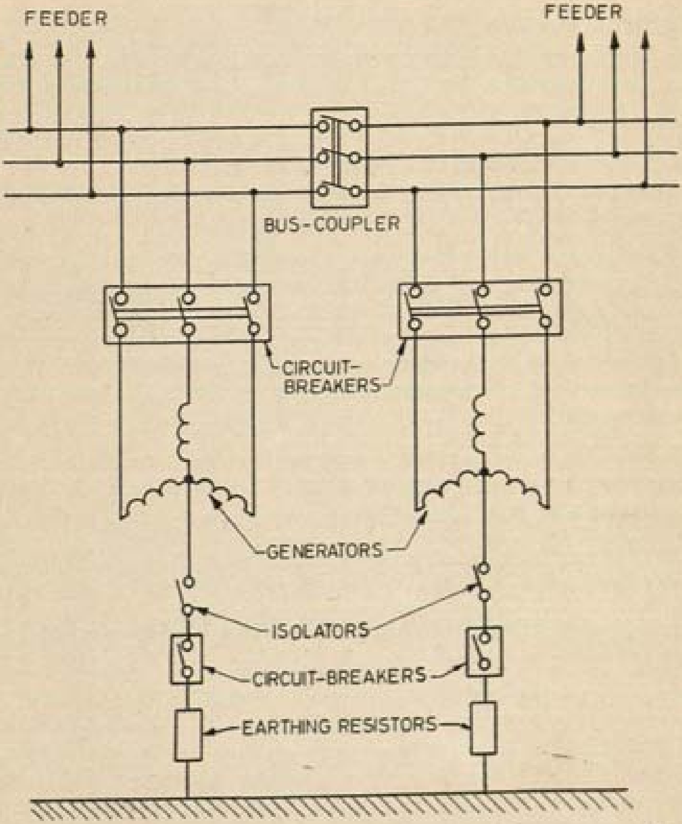


Fig. 19 Earthing of Generators Through Individual Resistors

17.7.4 *Generators Connected to Overhead Lines* — If the generators are connected directly to systems comprising exposed overhead lines, they get subjected to the effects of travelling waves or impulses due to lightning. In such a case if the neutral is earthed through a reactance, positive reflection of the waves can take place and may subject the winding insulation to damaging stresses. To prevent this, the reactor shall be shunted by a non-linear resistance which will limit the surge voltage to such a value which the machine can safely withstand. Surge arresters may also be connected to the machine terminals to give the same effect.

17.7.5 *Resistors for Field Circuits* — Resistors used in the field circuit of generators, synchronous condensers, motors, etc, should have their frames earthed.

17.8 Earthing of Lightning Arresters

17.8.1 The bases of lightning arresters shall be directly connected to the earth by conductors as short and as straight as practicable to ensure minimum impedance. In addition, there shall be as direct a connection as practicable from the earth side of the lightning arresters to the frame of the apparatus being protected. Surge counters, however, may be inserted in the circuit, but in such cases the lightning arrester should be mounted on an insulated base.

17.8.2 Individual earth electrodes should be provided for each station type lightning arresters while for distribution type lightning arresters one earth electrode may be provided for a set of lightning arresters. Separate earth electrodes for lightning arresters are provided for the reason that large earthing systems in themselves may be relatively of little use for lightning protection. These earth electrodes should be connected to the main earth system.

17.8.3 For lightning arresters mounted near transformers, earthing conductors shall be located clear of the tank and coolers in order to avoid possible oil leakage caused by arcing.

17.8.4 The earth connection should not pass through iron pipes as it would increase the impedance of the connection.

17.9 Earthing of Miscellaneous Substation and Generating Station Apparatus

17.9.1 *Disconnecting Switches* — In the case of isolated-phase systems, disconnecting switches tied to the main bus-bar should have their bases earthed with connections equal in cross-section to the earth bus. In the case of group arrangements where the disconnecting switch bases are mounted directly on masonry and the fault-bus system is not used, no provision be made for earthing the switch bases*.

---

*It is recognized that in following out this suggestion there is a possibility of fault currents attempting to find a path through the reinforcing steel and structural steel of the building. It is thought, however, that this danger is not sufficiently great to justify earthing the bases of disconnecting switches so mounted. The only reason for earthing the bases of disconnecting switches is to provide a path to earth which shall have a resistance less than the path provided by the reinforcing steel and structural steel of the building.

17.9.2 *Instrument Transformers*

17.9.2.1 Cases or frames of instrument transformers shall be earthed.

17.9.2.2 *Current transformers* — The secondary windings of current transformers shall be earthed. This may be done by connection to the earth bus.

In case of isolated-phase arrangements current transformers should have their feet or enclosing cases earthed with a connection equal in carrying capacity to the main lead, but in no case need this connection be of larger carrying capacity than the main earth bus. In the case of group arrangements the metal supporting framework for the current transformers should be earthed. This earthing should be done at one point only in order to prevent circulating currents between earthed points which may affect relay or meter performance.

17.9.2.3 *Voltage transformers* — The secondary windings of voltage transformers shall be earthed. This may be done by connection to the earth bus.

When voltage transformers are mounted in masonry compartments, whether the isolated or the group arrangement is used, they should have their cases earthed with a connection of sufficient size to be mechanically strong. This should be equal in carrying capacity to the primary lead and in no case should be smaller than the earth bus size. When voltage transformers are mounted on supporting framework, this framework should be earthed.

17.9.3 *Power Circuit-Breakers* — The earth connection for power circuit-breakers is limited to the amount of current that can be passed through the frames of the breakers to the point where suitable earth connection can be made. The size of earthing lead shall be in accordance with **17.3.2.**

17.9.4 *Rods or Handles of Outdoor Gang-Operated Isolators* — The operating rods or handles of all outdoor gang-operated isolators should be connected to earth either directly or through the steel mounted structure. The earth connection to the operating rod or handle should be made directly above the operating handle.

Two alternative methods are used for providing added safety by furnishing a construction for the operator to stand upon while operating the switch:

a) an earthed metal mat, or

b) an insulated platform, either portable or stationary.

The earthed metal mat should be connected to the operating rod above the switch handle and should also be connected to the station earth bus.

The metal mat should be galvanized steel plate or equivalent and the earthing lead should be connected to the plate by a minimum of two bolted-type terminals. Soldered connections should not be used. Safety depends upon maintaining good connections.

In the case of the insulated platform there is the same low resistance path from the operating pipe to earth while the operator is insulated from earth. Maximum safety depends upon maintaining good insulation for the platform and good connections.

Wooden switch handles may be used. They should be removable and protected from the weather when not in use; otherwise they may prove to be hazardous.

Where metal handles are used, it is recommended that the operator should wear rubber gloves when operating the isolator.

Isolators are sometimes mounted on wooden poles in order to use the insulating value of the wooden structure to supplement the insulation of the switches. In this case, the vertical operating rod of the isolator is usually insulated and the switch bases are not earthed. The operating pipe below the insulation should be earthed.

17.9.5 *Cases of Instruments, Meters and Relays (Operating Voltage Up to 650 Volts)* — Instruments, meters and relays with windings or working parts at 650 volts or less shall be earthed as follows:

a) *Not situated on switchboards* — Instruments, meters and relays not located on switchboards, and accessible to other than qualified persons, shall have their cases and other exposed metal parts earthed.

b) *On dead front switchboards* — Instruments, meters and relays (whether operated from current and voltage transformers, or connected directly in the circuit) on switchboards having no live parts on the front of the panels shall have their cases earthed.

c) *On live front switchboards* — Instruments, meters and relays (whether operated from current and voltage transformers, or connected directly in the circuit) on switchboards having exposed live parts on the front of panels shall not have their cases earthed. Rubber mats, or other suitable floor insulation, shall be provided for the operator.

17.9.6 *Cases of Instruments, Meters and Relays (Operating Voltage Above 650 Volts)* — Where instruments, meters and relays have current-carrying parts over 650 volts to earth, they shall be isolated and be elevated or protected by suitable barriers, such as earthed metal or insulating covers or guards. Their cases shall not be earthed, except in electrostatic earth detectors where the internal earth segments of the instrument are connected to the instrument case and earthed. The earth detector shall be isolated by elevation.

18. EARTHING OF OVERHEAD POWER LINES

18.0 General — Earthing methods associated with overhead power lines, including the provision of aerial earth wires, the earthing of non-current-carrying metal work, and the bonding of such metal work, are designed for:

a) avoiding danger from a broken line conductor or from leakage due to breakdown of insulation, and to ensure that in such circumstances the protective gear will operate effectively;

b) ensuring, as far as possible, that the current in an earth wire or to support metal work due to lightning stroke shall be conveyed to earth without causing back flashover; and

c) minimizing inductive interference with communication circuits.

NOTE — An earth wire is effective in reducing electromagnetic induction if its resistance, including the resistance of tower footings and other connections to earth, completing the circuit with earth return, is small compared with its reactance at the frequency in question. At the fundamental frequency, a high-resistivity earth wire (steel wire) gives, therefore, practically no alleviation, even if it is perfectly earthed; a single low resistivity earth wire (hard-drawn copper of sufficient cross-section) may reduce the induced voltage.

18.1 Earthing of High-Voltage Lines

18.1.1 *Metal Work Bonded and Earthed at Each Support* — This is the simplest form of construction with steel towers but it is unsuitable for protection against lightning. It may be adopted for wooden pole lines also. The bonding and earthing of the metal work provides protection against the danger of pole top fires from leakage, provided the resistance to earth at each support is sufficiently low to permit protective gear to operate in the event of contact between a line conductor and earthed metal work.

18.1.2 *Metal Work Bonded and Connected to an Aerial Earth Wire* — The earth wire shall be connected to the neutral of the transformer or generator and shall be earthed at least on four towers in every 1·6 kilo-metre. This method provides protection against lightning also if the earth wire is run above the line conductors. For shielding the substation equipment against nearby lightning stroke a second earth wire may be run for a length of about 1·6 km from the substation.

The resistance of the earth wire to earth should be as low as possible. To avoid back flashover from the earthed metal work to the line conductors on the occurrence of a direct lightning stroke to the earth wire, it is recommended that the resistance in any tower footing or other connection of the aerial earth wire with earth should not be more than 0·02 ohm per kilovolt of minimum impulse flashover voltage of the insulators. If this value of the voltage is not known then a figure of 0·2 ohm per kilovolt of line voltage should be taken as a rough guide. However for overhead lines it is recommended that footing resistance should not be more than 10 ohms.

Earthing of pole top metal work should be avoided in regions where the soil resistivity is high unless careful attention has been paid to the electrode resistance in relation to the system voltage and the setting of the protective devices.

18.2 Earthing of Low-Voltage Lines

18.2.1 An earth wire may be run either above or below the phase conductors with suitable cradles or safety device from pole to pole so that in the event of breakage of any one of the phase conductors, it will make contact with the earth wire.

18.2.2 If wooden poles have been used, a bonding wire should connect all the metal work on the pole including the supporting metal work of all insulators.

18.2.3 All stay wires other than those which are connected with earth by means of a continuous earth wire shall be insulated to prevent danger from leakage. For this purpose an insulator shall be placed in each stay wire at a height of not less than 3 m from the ground.

19. MAINTENANCE OF EARTH ELECTRODES AT SUB-STATIONS AND GENERATING STATIONS

19.1 Records shall be kept of the initial resistance of substation and generating station earth electrodes and of subsequent tests carried out.

19.2 Normally annual measurement of earth resistance shall be carried out but local circumstances in the light of experience may justify increase or decrease in this interval but it should not be less than once in two years.

19.3 Periodical visual inspection of all earth electrode connection wherever available, shall be carried out to ensure their rigidity and other signs of deterioration.

19.4 In rural substations, particularly those connected to overhead high-voltage and low-voltage lines, greater reliance should be placed on the electrode system, and therefore facilities for testing the resistance of the electrode to general mass of earth, annually or as required by experience, should be provided.

19.5 Where installations are earthed to a metal sheath of the supply cable, it shall be verified periodically that the earth-fault loop is in a satisfactory state.

19.6 Where an installation is earthed to a cable sheath which is not continuous to the substation neutral (that is, there is an intervening section of overhead line without earth wire) a supplementary electrode system may be necessary. The adequacy of the electrode system shall be checked initially by an earth-fault loop test (*see* **11.1**).

19.7 The neighbouring soil to the earth electrode shall be kept moist, where necessary, by periodically pouring water through a pipe where fitted alongwith it or by pouring water in the immediate vicinity of the earth electrode.

20. MEASUREMENT OF EARTH RESISTIVITY

20.1 Test Locations

20.1.1 In the evaluation of earth resistivity for substations and generating stations, four or five test locations shall be chosen to cover the whole site. This number shall be increased for very large station sites or if the test results obtained at various locations show a significant difference, indicating variations in soil formation.

20.1.2 In case of transmission lines, the measurements shall be taken along the direction of the line, throughout the length approximately once in every 4 km.

20.2 Weather Conditions — The resistivity of earth varies over a wide range depending on its moisture content. It is, therefore, advisable to conduct earth resistivity tests during the dry season in order to get conservative results.

20.3 Principle of Tests

20.3.1 Wenner's four electrode method is recommended for these types of field investigations. In this method, four electrodes are driven into the earth along a straight line at equal intervals. A current I is passed through the two outer electrodes and the earth, as shown in Fig. 20 and the voltage difference V observed between the two inner electrodes. The current I flowing into the earth produces an electric field proportional to its density and to the resistivity of the soil. The voltage V measured between the inner electrodes is, therefore, proportional to this field. Consequently, the resistivity will be proportional to the ratio of the voltage to current.

The following equation holds for:

$$\rho = \frac{4s\pi \dfrac{V}{I}}{1 + \dfrac{2s}{\sqrt{s^2 + 4l^2}} - \dfrac{2s}{\sqrt{4s^2 + 4l^2}}} \qquad \text{............(1)}$$

where

ρ = resistivity of soil in ohm-metre,

V = voltage difference between the two inner electrodes in volts,

I = current flowing through the two outer electrodes in amperes,

s = distance between two successive electrodes in metres, and

l = depth of burial of electrodes in metres.

20.3.1.1 If the depth of burial of the electrodes in the ground 'l' is negligible compared to the spacing 's' between the electrodes then

$$\rho = \frac{2 \pi s V}{I} \qquad \text{............(2)}$$

20.3.1.2 Earth testers normally used for these tests comprise the current source and meters in a single instrument and directly read the resistance. The most frequently used earth tester is the four-terminal megger shown in Fig. 20.

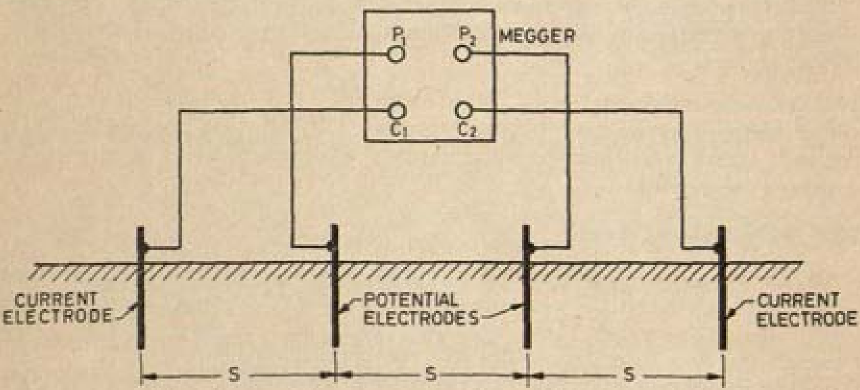


Fig. 20 Connections for a Four-Terminal Megger

When using such a megger, the resistivity may be evaluated from the modified form of equation (2) as given below:

$$\rho = 2 \pi s R \qquad \text{............(3)}$$

where

ρ = resistivity of soil in ohm-metres,

s = distance between successive electrodes in metres, and

R = megger reading in ohms.

20.4 Test Procedure

20.4.1 At the selected test site, four electrodes are driven into the earth along a straight line in the chosen direction, at equal intervals *s**. The depth of the electrodes in the ground shall be of the order of 10 to 15 cm. The megger is placed on a steady and approximately level base, the link between terminals, *P*1 and *C*1 opened and the four electrodes connected to the instrument terminals as shown in Fig. 20. An appropriate range on the instrument is then selected to obtain clear readings avoiding the two ends of the scale as far as possible. The readings are taken while turning the crank at about 135 rev/min.

Resistivity is calculated by substituting the value of *R* thus obtained in equation (3). In case where depth of burial is more than 1/20 of spacing, equation (1) should be used instead of (3).

20.4.2 *Correction for Potential Electrode Resistance* — In cases where the resistance of the potential electrodes (the two inner electrodes) is comparatively high, a correction of the test results would be necessary depending on its value. For this purpose the instrument is connected to the electrodes as shown in Fig. 21. The readings are taken as before. The correction is then effected as follows.

20.4.2.1 Let the readings of the megger be R_p with the connections as shown in Fig. 21, and the electrode spacings *s* metres. If the uncorrected value of soil resistivity is ρ and the resistance of the voltage circuit of the instrument used to obtain *R* (as indicated inside the scale cover of the meter) is R_v the corrected value of earth resistivity would be

$$\rho = \rho' \frac{R_p + R_v}{R_v}$$

20.5 Testing Soil Uniformity

20.5.1 During the course of above tests, it would also be desirable to get information about the horizontal or vertical variations in earth resistivity over the site under consideration. The vertical variation may be detected by repeating the tests at a given location with a number of different electrode spacings, increasing from 1 metre to 50 metres or more, preferably in the following steps 1, 5, 10, 15, 25, and 50 metres. If the resistivity variations are within 20 to 30 percent the soil in the vicinity of the test location may be considered uniform. Otherwise a curve of resistivity versus electrode spacing shall be plotted and this curve further analysed to deduce stratification of soil into two or more layers of appropriate thickness. For single rod and multiple rod installations, the resistivity value corresponding to a electrode spacing equal to the length of the rod

*Unequal spacing may also be used; but this makes the formula unnecessary complicated.

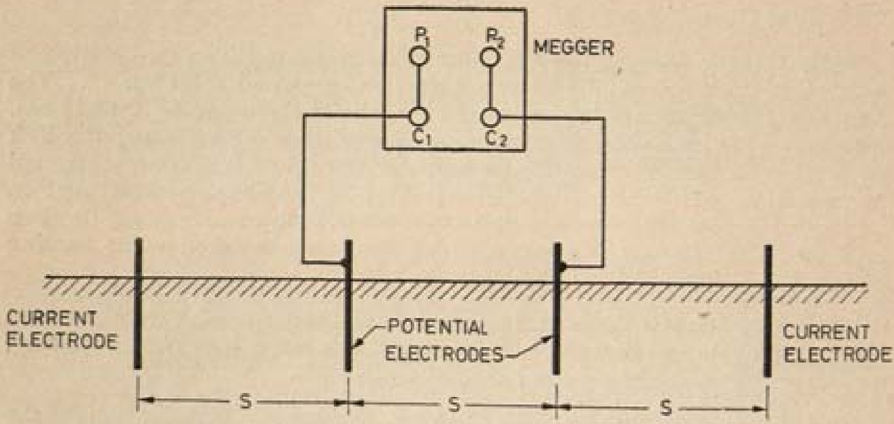


FIG. 21 TEST CONNECTION TO MEASURE THE SUM OF THE POTENTIAL ELECTRODE RESISTANCES

may be used in the empirical formulae, with reasonable accuracy, for precalculation of resistance.

The horizontal variation may be found out by comparing corresponding resistivity values obtained along the line route.

APPENDIX A

(*Clause* 4.1)

EXTRACTS FROM INDIAN ELECTRICITY RULES, 1956

Rule No. 32 Identification of Earthed and Earthed Neutral Conductors and Position of Switches and Cut-Outs Therein.

Where the conductors include an earthed conductor of a two-wire system or an earthed neutral conductor of a multi-wire system or a conductor which is to be connected thereto, the following conditions shall be complied with:

(1) An indication of a permanent nature shall be provided by the owner of the earthed or earthed neutral conductor, or the conductor which is to be connected thereto, to enable such conductor to be distinguished from any live conductor. Such indication shall be provided:

(a) Where the earthed or earthed neutral conductor is the property of the supplier, at or near the point of commencement of supply;

(b) Where a conductor forming part of a consumer's system is to be connected to the supplier's earthed or earthed neutral conductor at the point where such connection is to be made;

(c) In all other cases, at a point corresponding to the point of commencement of supply or at such other point as may be approved by an Inspector.

(2) No cut-out, link or switch other than a linked-switch arranged to operate simultaneously on the earthed or earthed neutral conductor and live conductors shall be inserted or remain inserted in any earthed or earthed neutral conductor of a two-wire system or in any earthed or earthed neutral conductor of a multi-wire system or in any conductor connected thereto with the following exceptions:

(a) A link for testing purposes, or

(b) A switch for use in controlling a generator or transformer.

Rule No. 51 Provisions Applicable to Medium, High or Extra High Voltage Installations — The following provisions shall be observed where energy at medium, high or extra-high voltage is supplied, converted, transformed or used:

(1) (a) All conductors (other than those of overhead lines) shall be completely enclosed in mechanically strong metal casing or metallic covering which is electrically and mechanically continuous and adequately protected against mechanical damage unless the said conductors are accessible only to an authorized person or are installed and protected to the satisfaction of the inspector so as to prevent danger.

(b) All metal work enclosing, supporting or associated with the installation, other than that designed to serve as a conductor shall, if considered necessary by the Inspector, be connected with earth.

(c) Every main switchboard shall comply with the following provisions, namely:

(i) a clear space of not less than 0·914 metre (3 feet) in width shall be provided in front of the switchboard;

(ii) if there are any attachments or bare connection at the back of the switchboard, the space (if any), behind the switchboard shall be either less than 0·229 metre (9 inches) or more than 0·762 metre (30 inches) in width, measured from the furthest outstanding part of any attachment or conductor;

(iii) if the space behind the switchboard exceeds 0·762 metre (30 inches) in width, there shall be a passage way from either end of the switchboard clear to a height of 1·829 metres (6 feet).

(2) Where an application has been made to a supplier for supply of energy to any installation, he shall not commence, or where the supply has been discontinued, recommence the supply unless he is satisfied that the consumer has complied in all respects with the conditions of supply set out in sub-rule (1) of this rule, rules 50 and 64.

(3) Where a supplier proposes to supply or use energy at medium voltage or to recommence supply after it has been discontinued for a period of six months, he shall before connecting or reconnecting the supply, give notice in writing of such intention to the inspector.

(4) If at any time after connecting the supplier is satisfied that any provision of sub-rule (1) of this rule, or of rules 50 and 64 is not being observed, he shall give notice of the same in writing to the consumer and the Inspector specifying how the provision has not been observed, and may discontinue the supply if the Inspector so directs.

Rule No. 61 Connection with Earth

(1) The following provisions shall apply to the connection with earth of systems at low voltage in cases where the voltage between phases or outers normally exceeds 125 volts and of systems at medium voltage:

(a) The neutral conductor of a three-phase four-wire system, and the middle conductor of a two-phase three-wire system shall be earthed by not less than two separate and distinct connections with earth both at the generating station and at the substation. It may also be earthed at one or more points along the distribution system or service line in addition to any connection with earth which may be at the consumer's premises.

(b) In the case of a system comprising electric supply lines having concentric cables, the external conductor of such cables shall be earthed by two separate and distinct connections with earth.

(c) The connection with earth may include a link by means of which the connection may be temporarily interrupted for the purpose of testing or for locating a fault.

(d) (i) In a direct current three-wire system the middle conductor shall be earthed at the generating station only, and the current from the middle conductor to earth shall be continuously recorded by means of a recording ammeter, and if at any time the current exceeds one-thousandth part of the maximum supply-current, immediate steps shall be taken to improve the insulation of the system.

(ii) Where the middle conductor is earthed by means of a circuit-breaker with a resistance connected in parallel, the resistance shall not exceed 10 ohms and on the opening of the circuit-breaker, immediate steps shall be taken to improve the insulation of the system, and the circuit-breaker shall be reclosed as soon as possible.

(iii) The resistance shall be used only as a protection for the ammeter in case of earths on the system and until such earths are removed. Immediate steps shall be taken to locate and remove the earth.

e) In the case of an alternating current system, there shall not be inserted in the connection with earth any impedance (other than that required solely for the operation of switchgear or instruments), cut-out or circuit-breaker, and the result of any test made to ascertain whether the current (if any) passing through the connection with earth is normal, shall be duly recorded by the supplier.

f) No person shall make connection with earth by the aid of, nor shall he keep it in contact with, any water main not belonging to him except with the consent of the owner thereof and of the Inspector.

g) Alternating current systems which are connected with earth as aforesaid may be electrically interconnected.

Provided that each connection with earth is bonded to the metal sheathing and metallic armouring (if any) of the electric supply lines concerned.

(2) The frame of every generator, stationary motor, and so far as is practicable, portable motor, and the metallic parts (not intended as conductors) of all transformers and any other apparatus used for regulating or controlling energy and all medium voltage energy consuming apparatus shall be earthed by the owner by two separate and distinct connections with earth.

(3) All metal casings or metallic coverings containing or protecting any electric supply-line or apparatus shall be connected with earth and shall be so joined and connected across all junction-boxes and other openings as to make good mechanical and electrical connection throughout their whole length:

Provided that where the supply is at low voltage, this sub-rule shall not apply to isolated wall tubes or to brackets, electroliers, switches, ceiling fans or other fittings (other than portable hand lamps and portable and transportable apparatus) unless provided with earth terminal.

Provided further that where the supply is at low voltage and where the installations are either new or renovated all plug sockets shall be of the three-pin type, and the third pin shall be permanently and efficiently earthed.

This sub-rule shall come into force immediately in the case of new installations and in the case of existing installations the provisions of this sub-rule shall be complied with before the expiry of a period of two years from the commencement of those rules.

(4) All earthing systems shall, before electric supply lines or apparatus are energised, be tested for electrical resistance to ensure efficient earthing.

(5) All earthing systems belonging to the supplier shall, in addition, be tested for resistance on dry day during the dry season not less than once every two years.

(6) A record of every earth test made and the result thereof shall be kept by the supplier for a period of not less than two years after the day of testing and shall be available to the Inspector when required.

Rule No. 62 Systems at Medium Voltage

Where a medium voltage supply system is employed, the voltage between earth and any conductor forming part of the same system shall not, under normal conditions, exceed low voltage.

Rule No. 67 Connection with Earth

(1) The following provisions shall apply to the connection with earth of three-phase systems for use at high or extra-high voltages:

In the case of star-connected systems with earthed neutrals or delta connected systems with earthed artificial neutral point:

a) the neutral point shall be earthed by not less than two separate and distinct connections with earth each having its own electrode at the generating station and at the substation and may be earthed at any other point provided that no interference of any description is caused by such earthing;

b) in the event of an appreciable harmonic current flowing in the neutral connection so as to cause interference with communication circuits, the generator or transformer neutral shall be earthed through a suitable impedance.

(2) Single-phase high or extra-high voltage systems shall be earthed in a manner approved by the Inspector.

(3) In the case of a system comprising electric supply-lines having concentric cables, the external conductor shall be the one to be connected with earth.

(4) Where a supplier proposes to connect with earth an existing system for use at high or extra-high voltage which has not hitherto been so connected with earth, he shall give not less than fourteen days' notice in

writing together with particulars to the telegraph-authority of the proposed connection with earth.

(5) Where the earthing lead and earth connection are used only in connection with earthing guards erected under high or extra-high voltage overhead lines where they cross a telecommunication line or a railway line, and where such lines are equipped with earth leakage relays of a type and setting approved by the Inspector, the resistance shall not exceed 25 ohms.

(6) In so far as the provisions of rule 61 are consistent with the provisions of this rule, all connections with earth shall also comply with the provisions of that rule.

Rule No. 69 Pole Type Substations

Where platform type construction is used for a pole type substation and sufficient space for a person to stand on the platform is provided, a substantial hand rail shall be built around the said platform and if the hand rail is of metal, it shall be connected with earth:

Provided that in the case of pole type substation on wooden support and wooden platform the metal hand-rail shall not be connected with earth.

Rule No. 88 Guarding

(2) Every guard-wire shall be connected with earth at each point at which its electrical continuity is broken.

Rule No. 90 Earthing

(1) All metal supports of overhead lines and metallic fittings attached thereto, shall be permanently and efficiently earthed. For this purpose a continuous earth wire shall be provided and securely fastened to each pole and connected with earth ordinarily at four points in every 1·609 km (mile), the spacing between the points being as nearly equidistant as possible. Alternatively, each support and the metallic fitting attached thereto shall be efficiently earthed.

(2) Each stay-wire shall be similarly earthed unless an insulator has been placed in it at a height not less than 3·048 metres (10 ft) from the ground.

APPENDIX B

(*Clause* 4.11)

LIST OF INDIAN STANDARDS REQUIRED FOR REFERENCE FOR EARTHING

IS : 280-1962	Specification for mild steel wire for general engineering purposes (*revised*)
IS : 434 (Part I)-1964	Specification for rubber-insulated cables : Part I With copper conductors (*revised*)
IS : 613-1964	Specification for copper rods for electrical purposes (*revised*)
IS : 692-1965	Paper insulated lead-sheathed cables for electricity supply (*revised*)
IS : 1079-1963	Specification for hot rolled carbon steel sheet and strip (*revised*)
IS : 1239-1964	Specification for mild steel tubes and tubulars (*revised*)
IS : 1293-1958	Specification for three pin plugs and socket outlets
IS : 1594-1960	Metric sizes of copper wires and conductors for electrical purposes
IS : 1653-1964	Specification for rigid steel conduits for electrical wiring (*revised*)
IS : 1897-1962	Specification for copper strip for electrical purposes with drawn or rolled edges
IS : 1972-1961	Specification for copper, plate, sheet and strip for industrial purposes

NOTE — Reference is also required to ISO Recommendation ISO/R13 Cast iron pipes.

APPENDIX C

(*Clause* 5.3.2)

REPRESENTATIVE VALUES OF SOIL RESISTIVITY IN VARIOUS PARTS OF INDIA

SL No.	LOCALITY	TYPE OF SOIL	ORDER OF RESISTIVITY IN ohm-metre	REMARKS
1.	Kakarapar, Surat Distt, Gujarat	Clayey black soil	6-23	Underlying bedrock-Deccan trap
2.	Taptee Valley	Alluvium	6-24	do
3.	Narmada Valley	Alluvium	4-11	Underlying bedrock-sand-stones, shale & limestones, Deccan trap & gneisses
4.	Purna Valley (Deogaon)	Agricultural	3-6	Underlying bedrock-Deccan trap
5.	Dhond, Bombay	Alluvium	6-40	do
6.	Bijapur Distt, Mysore State	a) Black cotton soil	2-10	do
		b) Moorm	10-50	do
7.	Garimenapenta, Nellore Distt, Andhra Pradesh	Alluvium (highly clayey)	2	Underlying bedrock-gneisses
8.	Kartee	a) Alluvium	3-5	Underlying bedrock-sand-stone, trap or gneisses
		b) Alluvium	9-21	
9.	Delhi			
	a) Najafgarh	a) Alluvium (dry sandy soil)	75-170	do
		b) Loamy to clayey soil	38-50	do
		c) Alluvium (saline)	1·5-9	do
	b) Chhatarpur	Dry soil	36-109	Underlying bedrock-quartzites

Sl No.	Locality	Type of Soil	Order of Resistivity in ohm-metre	Remarks
10.	Korba, MP	a) Moist clay b) Alluvium soil	2-3 10-20	Underlying bedrock-sand-stones or shale
11.	Cossipur, Calcutta	Alluvium	25 (approx)	—
12.	Bhagalpur, Bihar	a) Alluvium b) Top soil	9-14 24-46	Underlying bedrock-traps, sand-stones or gneisses
13.	Kerala (Trivandrum Distt)	Lateritic clay	2-5	Underlying bedrock-laterite, charnockite or granites
14.	Bharatpur	Sandy loam (saline)	6-14	—
15.	Kalyadi, Mysore	Alluvium	60-150	Underlying bedrock-gneisse
16.	Kolar Gold Fields	Sandy surface	45-185	do
17.	Wajrakarur, Andhra Pradesh	Alluvium	50-150	do
18.	Koyna, Satara Distt	Lateritic	800-1 200 (dry)	Underlying bedrock-sand-laterite or trap
19.	Kutch-Kandla, (Amjar Area)	a) Alluvium (clayey)	4-50	Underlying bedrock-sand-stone, shale or trap
		b) Alluvium (sandy)	60-200	do
20.	Villupuram, Madras	Clayey sands	11	Underlying bedrock-granite
21.	Ambaji, Banaskantha, Gujarat	Alluvium	170	Underlying bedrock-granites and gneisses
22.	Ramanathapuram Distt, Madras	a) Alluvium	2-5	Underlying bedrock-sand-stones and gneisses
		b) Lateritic soil	300 (approx)	do

NOTE — The soil resistivities are subject to wide seasonal variation as they depend very much on the moisture content.