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SAFETY ASPECTS OF ELECTRICAL EARTHING OF MINING MACHINERY

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1. *Introduction*

1.1 The term "Earthing" means connection of an electrical system to the general mass of earth. (Ref. 22)

1.2 An electrical system is said to be "neutral-earthed" (Ref. 2) when two conditions pertain:-

(i) The neutral point of the supply transformer secondary winding, or generator star-point, as the case may be, is connected to the general mass of the earth, either directly or via some current limiting device in the neutral connection to earth.

(ii) All metallic non-current carrying apparatus is continuously connected to the general mass of the earth, and also to the neutral point of the supply. (Ref. 21)

1.3 An isolated-neutral system (Ref. 2) is one in which:-

(i) The neutral point of the supply is not connected to earth, and

(ii) The metallic non-current carrying apparatus is continuously connected to earth, but is not connected to the neutral point of the supply.

1.4 The hazards associated with each type of system will be outlined, with references to the bibliography listed at the end of this paper from which more detailed information can be obtained for those interested.

2. *Reasons for Earthing*

2.1 An electrical system is earthed to achieve two major objectives:-

(i) to reduce to a minimum the danger of electric shock to operating personnel and the general public.

(ii) to protect electrical equipment from the damage which results from breakdown of insulation.

2.2 These objectives are attained by providing:-

(i) protection against dangerous potential gradients which result from earth fault currents in equipment (Ref. 34);

(ii) protection from lightning discharges and electrostatic effects which are produced by moving bodies;

(iii) correctly rated protective devices such as fuses, circuit breakers (Ref. 3) and earth leakage equipment (Ref. 24) which will isolate a fault before the arcing, which results from the fault currents flowing from the active conductors to the metal frames of the equipment, can cause destructive mechanical damage and fires, and before the gradient potentials mentioned in (i) can attain and keep dangerous values.

2.3 The above objectives may be summed up by stating that if all exposed metal parts of an installation, such as conduits, motor frames, switchgear cases etc., are connected via a low resistance path to earth (Ref. 21) then in the event of a failure of insulation leading to contact between live conductors and exposed metal, the earth fault current which will flow will cause the protective devices to operate, and so isolate the defective part of the installation.

2.4 In practice an effective contact with the general mass of the earth is effected by driving steel or copper rods into ground of suitable resistivity (Ref. 45) or burying copper plates or cast ironwork, and connecting thereto a cable of low ohmic resistance to which all metal frames of electrical equipment are solidly and continuously joined.

2.5 With a neutral-earthed system, the neutral point of the supply is also connected to this same earth electrode.

3. *Electric Shock Hazards*

3.1 At this juncture it may be fitting to point out that it is important that operating personnel and the public generally should know the unsafe circumstances against which protection should be provided in the event of possible breakdown of insulation.

3.2 It is also important that people should know how and in what degree an electric shock can occur to them (Ref. 1) in order that they should appreciate fully the reasons for preventing electrical faults and the importance of earthing. Further details are therefore given in 3.3 to 3.7 inclusive.

3.3 There are three most common sources of electric shock. These are:-

(i) Direct contact with a live conductor or part of live equipment.

(ii) Potential rise on the earthed frame of a consuming device brought about by leakage from defectively insulated conductors within the device.

(iii) Voltage gradients formed by the passage of heavy fault currents from the electrical reticulation into the general mass of earth.

3.4 The most likely conditions that could cause an electrical installation to deteriorate and breakdown, giving rise to the dangers mentioned in (ii) and (iii) in 3.3 above, are:-

(i) Where excessive vibration exists, such as on a vibrating screen at a mine.

(ii) In humid or damp atmospheres - this is a fairly common condition in mines.

(iii) On portable and mobile machines - such as shuttle cars - loaders, boring machines etc.

(iv) Where the standard of protection equipment and conductors is poor or inadequate for the rated duty of the machines.

(v) Where no regular maintenance is carried out, or where the maintenance is performed by incompetent persons.

3.5 Most of the electrical Regulations in the Mining Acts are designed to cover the forementioned situations, but are too numerous to quote for the purposes of this paper.

3.6 To elaborate, it is obvious that direct contact with live apparatus must be avoided. There are no known protective devices which will prevent a shock, usually fatal, being given to a person touching live apparatus, and in fact any voltage above 20 Volts alternating current could be dangerous to humans.

3.7 However the dangers arising from conditions 3.3 (ii) and (iii) are not obvious, and a detailed explanation is given in the Appendix of this paper.

4. *Earthing in Mines*

4.1 Earthing practice in mines introduces some aspects which necessitate variations from the Standard Codes (Ref. 56) on earthing which various technical bodies have drawn up.

4.1.1 Of the three recognised systems of earthing, viz.

(i) The direct earthing system.
(ii) The multiple Earth Neutral (M.E.N.) system (Ref. 17, 18, 56)
(iii) The earth leakage circuit breaker system.

Only (i) and (iii) are applicable to underground installations.

4.1.2 System (ii) cannot be adopted because of the uncertainty of the resistance of the rock strata (Ref. 6) which varies according to the dampness and chemical and mineral content of the rock or ore bodies, and also the deleterious effect of acid waters on the earthing equipment.

4.1.3 In a mine the earth conductors from all machines are taken up the shaft or tunnel to the surface and there joined to the main earth system.

4.1.4 Because of the long distances involved, which could be many miles from the furthermost workings of the mine to the surface, care must be taken that the earth conductor is of sufficiently low resistance and adequate current carrying capacity (Ref. 11) to enable fault currents to be controlled by the protective equipment.

4.1.5 Contrary to outside practice also, it is not advisable to bond the electrical earthing system with other service mains such as compressed air lines, water pipes, rails etc., which exist in a mine, because of the danger of sparking at joints and breaks in these other service mains under earth fault conditions (Ref. 34).

4.1.6 Again because of the complexity of a mine installation, which might involve many underground substations and a variety of voltages, it is not practicable to separate the high tension earthing system (Ref. 29) from the low or medium voltage systems, (Ref. 21) so that a common earth conductor must be used.

4.1.7 The bonding of high and low tension earths is not recommended by Standard Codes unless the resistance of the earthing system is kept below one ohm. This figure is not always possible to obtain in mining areas and in many cases elaborate interconnection of surface substation earth systems must be made in order to get as low a resistance as possible.

5. *Protective Devices*

5.1 With the neutral-earthed systems, earth fault conditions may be controlled by:-

(i) Resistance in the neutral-earth connection to limit the earth current (Ref. 2).

(ii) Fuses on each subcircuit (Ref. 3).

(iii) Circuit breakers with overload protection (Ref. 3).

(iv) Earth leakage circuit breakers (Ref. 24).

5.1.1 Methods (ii), (iii), and (iv) each give selective isolation of faults without disturbing the rest of the system, but both fuses and overloads do not operate until the earth fault has reached high current values, in some cases 100% greater than the normal working current of the circuit.

5.1.2 This characteristic has the disadvantage of allowing the fault currents to cause considerable damage to apparatus from the arcing and in many cases cause fires, quite apart from the creation of high potential gradients on the equipment.

5.1.3 With core balance earth leakage protection, the relays may be set to trip at very low fault values, of the order of 5-20 ma in some cases, with a tripping time of 0.03 seconds, thus providing personal protection as well as limiting the duration of the arcing time of the fault current.

5.2 With isolated-neutral systems, the occurrence of an earth fault on one phase does not permit much ground current to flow and hence does not normally cause voltage gradients which creates a shock hazard.

5.2.1 However such systems are subject to simultaneous ground faults, i.e. faults on more than one line, or phase, sometimes at different places, with the net result of a line to line fault.

5.2.2 Often when the first earth fault occurs, nothing is done about it immediately, hence if a second fault occurs before the first has been removed, the line-to-line fault conditions exist.

5.2.3 When the line to line fault occurs, the current between the two faults is limited only by the impedence of the system elements, and therefore the fault current is quite high and can produce unsafe voltages and expose personnel to very high shock hazards.

5.3 With the exception of the current limiting resistance in the neutral, the same protective devices which apply to the earth-neutral system also apply to the isolated-neutral system.

5.4 The same drawbacks apply with fuses and overloads, and a similar core balance device as used on the earthed system would be much less sensitive on the isolated-neutral system, and in addition, could not give selective switching.

5.5 However, other instruments have been devised which do give sensitive operation, so that single line to earth faults can be detected and the circuit isolated before line to line faults can occur (Ref. 1).

6. *Lightning Considerations*

6.1 Lightning impulse voltages are characterized by steep-wave-front voltage surges of short duration, which travel along an electric conductor in the manner of a wave. Such voltages may be imparted to the electric distribution system by direct contact of a lightning stroke, or by induction as a result of a nearby lightning discharge. Lightning impulse voltages originating on the high-tension supply system will, in general, be transmitted through the substation step-down transformers, reduced in magnitude, approximately the same as the normal transformation ratio.

6.1.1 Voltage and current magnitudes, associated with the direct discharge may be very high - thousands of amperes and millions of volts. Most of this surge will pass on to earth at the location of the discharge stroke, since the electric circuits with which we are dealing, are incapable of supporting such high voltage levels. A minor surge, whose peak value does not exceed the flashover limits of the line, will be transmitted along the electric-circuit conductor away from the point of discharge.

6.1.2 For a short-time, steep-wave-front impulse surge the impedence represented by the electric conductors is very much higher than the normal 50-cycle value and will ordinarily be in the order of 200 to 500 Ohms. The effectiveness of earth connections along the transmission-line circuits is consequently much greater for impulse surges than for normal 50-cycle currents.

6.2 The minimum electric shock current which will produce injury to personnel, becomes greater as the duration diminishes. Strangely enough, the boundary relationship for shock hazard is represented by a constant of value of $I^2 t$. For a current duration of 100 micro-second (1/10,000 second), a current of 16 amp. could be permitted before the fatal shock boundary is reached for an adult.

6.2.1 It may be reasonably concluded that lightning impulse voltages, originating on the pole-line distribution system, or on the primary high-tension supply system, can be easily dissipated and not constitute a serious hazard to personnel working near mobile or portable machines such as used in quarries and open cut mines. The lightning protective problem for the distribution system thus becomes one of adequately protecting electrical equipment which forms a part of that system.

6.2.2 Yet the shock hazard associated with a direct lightning stroke to a mobile or portable machine is a real one and extremely difficult to eliminate. Numerous possible protective systems have been investigated but all involve a large number of driven rods or metal mats surrounding the mobile or portable machine. This seems hopeless to attain in practice. Often a thunderstorm means a temporary shutdown of operations anyway. Thus during the danger period of the storm, the personnel should seek shelter in the metal cab of the machine or at a spot well removed from the machine. To stand on the ground near a mobile or portable machine is about as dangerous as standing under a tree.

6.3 The lightning protective equipment at the main substation should consist of the protective devices which would normally be applied to a substation of the same size and voltage ratings. Lightning arrestors should be applied at the junction of the trailing cable and the pole-line feeder to limit the maximum line-to-earth voltage permitted. Surge protective capacitor equipment should be applied on the load side of the circuit breaker, within the portable machine, to reduce the slope of the wave front for the protection of rotating machines. A fairly good driven earth should be established at the tap-off station, to which the earth leads from all lightning protective devices should be connected.

6.4 One important point concerning the design of the main substation should be mentioned here. The earth-fault current which may be supplied by the high-voltage supply system, is not controlled by the local electric system design and may often be quite large. Any line-to-earth flashover at the main substation will allow the high-voltage system earth current to flow into the main substation earth. This current would persist for a time interval governed by the switching time of the high-voltage protective circuit breaker. A 5,000-amp. earth-fault current (which might easily be equalled or exceeded), in combination with the main substation earth resistance of 2 Ohms would cause the entire main substation structure to be elevated 10,000 v. with respect to the earth, and remain at this potential until the high-voltage system protective circuit breaker operated (probably ¼ to 1 second). If the mobile or portable-machine circuit protective earth were physically interconnected with the main substation earth, it is obvious that this high potential would be distributed to the frames of all mobile or portable machines and thus constitute a serious hazard.

6.5 As a result of these considerations, it is recommended that the protective earth circuit, originating at the step-down transformer low-voltage neutral, be insulated from the main substation earth system with the same insulation level as applied to the low-tension line circuit, and earthed at an adjacent separate earthing connection. The voltage gradient in the earth surrounding the main substation diminishes very rapidly as one moves away from the substation. In general a 50 ft separation between the two earthing terminals is sufficient to avoid any substantial coupling between the two earth beds, and any direct interconnection between these two earths such as buried metal pipe lines, etc. should be avoided.

7. *Summary*

7.1 Because this paper is intended to refer to safety aspects of earthing for mines in particular, a brief list of precautions to be taken to avoid danger from fault currents in mining installations may be as follows:-

(i) Because fault currents can be limited by resistance in the neutral connection to earth, and the earthed-neutral system lends itself to easy control by relays which afford discrimination as well as protection to personnel, the earthed-neutral system is to be recommended for use in mines.

(ii) All non-current carrying metal parts of electrical plant should be continuously earthed by conductors of adequate cross section and connected to a main substation earth-bed at the surface of the mine.

(iii) The main system earth at the surface should not be connected to earthing systems designed for lightning protection.

(iv) Steelwork, pipes, ropes etc. inside the mine and shafts should be bonded for lightning protection, but not connected to the main system earth.

(v) A main system earth should be carefully designed so that the total resistance including the earth electrodes is less than 1 ohm.

(vi) Earth electrodes should not be used in the mine underground workings.

8. *Appendix—Electric Shock Hazards*

For a current to pass through a conductor, whether the conductor be a wire or the human body, there must be a difference of potential between the ends of the conductor or body, as the case may be.

A basic electrical formula is Ohm's Law, which states that the current in a conductor is equal to the potential difference between the ends of the conductor divided by the electrical resistance of the conductor.

The practical unit of current is the Ampere; the unit of potential difference is the Volt; the unit of resistance is the Ohm.

$$\text{Thus Amps} = \frac{\text{Volts}}{\text{Ohms}}$$

$$1 \text{ milliampere} = \frac{1}{1000} \text{ Ampere}$$

It has been established elsewhere that the electrical resistance of the human body is about 600 - 1500 Ohms, depending on the body condition, such as dampness etc.

To appreciate just what an electric shock means, the following figures are quoted:-

8.1 Human Resistance to Electrical Current

Type of Resistance	Resistance Values, Ohms
Dry Skin	100,000 to 600,000
Wet Skin	1,000
Internal body-hand to foot	400 to 600
Ear to ear	about 100

8.2 Effects of Current on Human Beings

Current Reading	Effects
1 millampere or less	Causes no sensation, not felt.
1 to 8 ma.	Sensation of shock, not painful, individual can let go at will because muscular control is not lost.
8 to 15 ma.	Painful shock, individual can let go at will because muscular control is not lost.
15 to 20 ma.	Painful shock; muscular control may be lost and cannot let go.

20 to 50 ma.	Painful; severe muscular contraction breathing difficult. Ventricular Fibrillation may occur, which is a heart condition that can result in death.
50 to 100 ma.	Ventricular Fibrillation occurs. Possible death to the individual.
100 to 200 ma.	Ventricular Fibrillation occurs. Usually certain death.
200 and over.	Severe burns, severe muscular contractions - so severe that chest muscles clamp heart and stop it during duration of shock.

8.3 Formula

$$\text{Current through body} = \frac{\text{Voltage applied to body}}{\text{resistance of body plus contact resistance}}$$

Shock severity depends upon the following factors:

(1) Becomes more severe with increased voltage applied.
(2) Increased due to the amount of moisture on contact surfaces.
(3) Increased with an increase in pressure of contact.
(4) Increased with an increase in area of body contact.
(5) Resistance of body portions.

8.3.1 Practical Problem

A worker with wet clothes or wet with perspiration comes in contact with a defective 120 V light cord and establishes a good ground.

From Preceding Table

Wet skin resistance	1,000 Ohm
Internal resistance	500 Ohm
	1,500 Ohms

$$\text{Current through body} \quad \frac{120 \text{ volts}}{1{,}500 \text{ Ohm}} = 80 \text{ ma}$$ (note that muscular control is lost and that man cannot break contact).

As the contact is continued, the skin resistance is reduced. If the skin is punctured, the skin resistance may then be disregarded. Then for practical purposes, the total resistance of the worker may be in the neighbourhood of 600 ohm.

$$\text{Current through body} = \frac{120}{600} = 200 \text{ ma (Certain death).}$$

8.4 Other sources of shock:-

Suppose we have a motor connected to a 415 Volt circuit. The frame of the motor is earthed by means of an earth wire having resistance of 5 ohms to the main earth electrode of a mine. Now further suppose that due to dampness the insulation of the motor windings has broken down and a fault current of 10 Amps is leaking to earth via the frame of the motor and earth wire.

The potential difference between the motor frame and earth is then 5 x 10 = 50 Volts.

Thus if a man, whose body resistance was 1000 Ohms, touched the motor frame whilst standing on the ground, a current of $\frac{50}{1000}$ = 50 ma., would flow through his body, and as shown in the table, he would receive a shock which could prove fatal.

8.5 In order to prevent such a dangerous situation, protective devices, such as core balanced earth leakage units, are coupled in the circuit, which cut off the source of supply to the motor if the fault current exceeds a certain figure, usually about 3% of the total working current of the motor.

In addition the conductance of the earth wires is kept at such a figure that the resistance to the earth connection is very low, usually not more than 1 Ohm.

Thus if the full load current of a motor was 100 Amps and the protective device was set to trip at 3%, or 3 Amps, and the earth wire resistance was 1 Ohm, then the power to the motor would be cut off when the potential to earth was 3 x 1 or 3 Volts, which would be harmless.

8.6 Again assume a 100 HP motor protected only by fuses, full load current 100 Amps.

The fuses are rated at 200% of the working load of the motor, or 200 Amps. The earth wire remains at 1 Ohm.

When a fault develops, the fuses will not blow until the full 200 Amps are flowing to earth.

The resultant potential at the motor frame would then be 200 x 1 = 200 volts.

If a man touched the frame of the motor whilst standing on the ground, the current through his body would be $\frac{200}{1,000}$ = 200 millamps, which could be fatal.

This also illustrates that fused circuits do not give protection against leakage currents of a lesser value than the full rated current carrying capacity of the fuse.

8.7 Similarly, if a heavy fault current was flowing along an exposed conductor, such as the armouring of a cable, sufficient potential difference could occur at points a yard apart along the length of the cable, which if touched by the hand, could give a fatal shock.

It might be mentioned that under some short circuit conditions, fault currents of 10,000 Amps or more could be encountered.

8.8 So that it can be seen that if an electrical installation is not installed and maintained correctly and thoroughly then danger can exist in many circumstances.

9. *Bibliography*

1 International Symposium on Electrical Accidents
International Occupational Safety & Health Information Centre (C.I.S.) Paris, May 1962.

2. The J. & P. Transformer Book.

3. The J. & P. Switchgear Book.

4. Earthing Principles and Practice.
R. W. Ryder. A small, but useful, book published by Isaac Pitman & Sons Ltd., in 1952.

5. An Investigation of Earthing Resistances.
P. J. Higgs. Journal I.E.E., Vol. 68, 1930.

6. Earth Resistivity and Geological Structure.
R. H. Card, Transactions Am.I.E.E., Vol. 54, 1935.

7. Calculation of Resistance to Ground.
H. B. Dwight. Transactions Am.I.E.E., Vol. 55, 1936.

8. Grounding Principle & Practice - Fundamental Considerations on Ground Current.
R. Rudenburg. Elec. Engineering (Am. I.E.E.), Jan. 1945.

9. Grounding Principle & Practice - Establishing Grounds.
Claude Jensen. Elec. Engineering (Am.I.E.E.), Feb. 1945.

10. The Resistance of Earth Electrodes.
P. D. Morgan & H. G. Taylor, E.R.A. Report F/T 50, 1932;
also Journal I.E.E., Vol. 72, 1933.

11. The Current Loading Capacity of Earth Electrodes.
H. G. Taylor, E.R.A. Report F/T 81, 1934; also Journal I.E.E., Vol. 77, 1935.

12. Impulse and 60 cycle Characteristics of Driven Grounds (Electrodes).
P. L. Bellaschi. Elec. Engineering (Am.I.E.E.), March 1941.

13. A Review of Recent Development in Rural Electrification - Section 9: Earthing.
D. Ross. Journal I.E.E., Vol. 77, 1935.

14. The Earthing Question.
W. R. Kemp. Journal I.E. Aust., Vol. 7, 1935

15. Practical Aspects of Earthing.
E. Fawsett, H. W. Grimmitt, G. F. Shotter & H. G. Taylor.
E.R.A. Report Trans./T 149, 1941; also Journal I.E.E., Vol. 87, 1940.

16. Grounding Electrical Circuits Effectively.
J. R. Eaton. G. E. Review Nos. 6, 7 and 8, Vol. 44, 1941.

17. The Use of Protective Multiple Earthing and E.L.C.B. in Rural Areas (First Report).
H. G. Taylor. E.R.A. Report F/T 112, 1938; also Journal I.E.E. Vol. 81, 1937.

18. The Use of Protective Multiple Earthing and E.L.C.B. in Rural Areas (Second Report).
H. G. Taylor. E.R.A. Report F/T 146, 1942; also Journal I.E.E., Vol. 88, 1941.

19. Earthing Problems.
R. W. Ryder. Journal I.E.E., Vol. 95, Part II, 1948.

20. Cost and Efficiency of Earthing on Low and Medium Voltage Overhead Line Systems.
L. Gosland. Proceedings I.E.E., Vol. 97, Part II, 1950.

21. Earthing of Low and Medium Voltage Distribution Systems and Equipment.
F. Mather. Proceedings I.E.E., Vol. 105, Part A, 1958.

22. The Principles of Earthing.
Technical data issued by the Electricity Authority of New South Wales.

23. Correction Nomograms for Earth Testing Instruments.
Technical data issued by the Electricity Authority of New South Wales (Circular No. 365).

24. Earth Fault and Earth Continuity Protective Systems as Applied to Mining.
E. T. Faulkner. Electric Control Engineering Company.

25. Humphries, J. D. - Earth-Electrode Systems for Large Electric Stations.
Proc. I.E.E. Pt. A, Vol. 104, No. 17, Oct. 1957, p. 383, (Paper No. 2341S).

26. Schwarz, S. J. - Analytical Expressions for the Resistance of Grounding Systems.
Trans. A.I.E.E. Pt. III-B, Vol. 73, Aug. 1954, p. 1011, (Paper No. 54-201).

27. Dwight, H. B. - Electrical Coils and Conductors. New York, McGraw-Hill, 1945, p. 57.

28. McCrocklin, A. J. and Wendlandt, C. W. - Determination of Resistance to Ground of Grounding Grids. Trans. A.I.E.E. Pt. III, Vol. 71, Dec. 1952, p. 1062.

29. Gross, E. T. B., Chitnis, B. V. and Stratton, L. J. - Grounding Grids for High Voltage Stations. Trans. A.I.E.E. Pt.III, Vol. 72, Aug. 1953, p. 799, (Paper No. 53-239).

30. Zaborzky, J. and Rittenhouse, J. W. - Design Charts for Determining Optimum Ground-Rod Dimensions. Trans. A.I.E.E. Pt. III, Vol. 72, Aug. 1953, p. 810 (Paper No. 53-240).

31. A.I.E.E. Committee Report. Application Guide on Methods of Substation Grounding. Trans. A.I.E.E. Pt. III-A, Vol. 73, April, 1954, p. 271, (Paper No. 54-81).

32. Copper for Earthing. Copper Development Association, Publication No. 30, 6th impression, 1954.

33. A.I.E.E. Committee Report. Safety in A.C. Substation Grounding.
Electrical Engineering, Vol. 79, Jan. 1960, pp. 65-7.

34. A.I.E.E. Committee Report. Voltage Gradients through Ground under fault Conditions. Trans. A.I.E.E. Pt. III, Vol. 77, Oct. 1958, pp. 669-85, (Paper No. 58-98).

35. Kennelly, A. E. - Capacity of Electrical Cables, Submerged, Buried or Suspended in Air. Electrical World, Vol. 22, 1893, p. 183.

36. Eaton, J. R. - Impulse Characteristics of Electrical Connections to the Earth. General Electric Review, Vol. 47, Oct. 1944, p. 41.

37. Bellaschi, P. L. and Armington, R. E. - Impulse and 60-Cycle Characteristics of Driven Grounds - III Effect of Lead in Ground Installation. Trans. A.I.E.E., Vol. 62, 1943, p. 334, (Paper No. 43-12.)

38. Earth Resistance Measurement. Evershed and Vignoles Ltd., Chiswick, London.

39. Picken, D. A. - The Effects of Electricity on Human Beings. Proc. I.E.E. Pt. A, Vol. 108, No. 37, Feb. 1961, p. 25, (Abstract No. 3492).

40. Ferris, L. P., King, B. G., Spence, P. W. and Williams, H. B. - Effect of Electric Shock on the Heart. A.I.E.E. Elec. Engg., Vol. 55, May 1936, p. 498.

41. Laurent, P. G. - Les Bases Generales de la Technique des Mises a la Terre dans l'Installation Electrique. Bulletin Societe Francaise des Electriciens, (Series 7), Vol. 1, July 1951, pp. 368-402.

42. Dalziel, C. F. - A Study of the Hazards of Impulse Currents. Trans. A.I.E.E. Pt. III, Vol. 72, Oct. 1953, p. 1032, (Paper No. 53-313).

43. Dalziel, C. F. and Massoglia, F. P. - Let Go Currents and Voltages. Trans. A.I.E.E. Pt. II, Vol. 75, May 1956, p. 49, (Paper No. 56-11).

44. Resistivity Prospecting. Evershed and Vignoles Ltd., Chiswick, London. Publication No. 245.

45. Armstrong, H. R. - Grounding Electrode Characteristics from Model Tests. Trans. A.I.E.E. Pt. III, Dec. 1953, p. 1301, (Paper No. 53-398).

46. Dalziel, C. F. - Threshold 60-Cycle Fibrillating Current. Trans. A.I.E.E. Pt. III, Vol. 77, Oct. 1960, p. 667, (Paper No. 60-40).

47. Abrahams, M. - The Classical Theory of Electricity and Magnetism. London, Blackie, 1947.

48. Kouwenhoven, W. B., Knickerbocker, G. C. Milnor, W. R. and Jude, J. R. - Field Treatment in Electric Shock Cases. - II Trans. A.I.E.E. Pt. III, Vol. 79, April 1960, p. 19, (Paper No. 60-171).

49. Byerly, W. E. - Fouriers Series and Spherical, Cylindrical and Ellipsoidal Harmonics. Boston, Mass., Ginn and Co., 1893.

50. Weinback, M. P. - Electric Power Transmission. New York, Macmillan, 1948, p. 362.

51. Baxter, H. W. and Taylor, H. G. A Low-Range Earth Tester. Electrical Research Association, E.R.A. Report No. F/T 85, 1935, p. 9.

52. Gray, D. E., ed. - American Institute of Physics Handbook.
2nd ed. New York, McGraw-Hill, 1963.

53. Mines Inspection Act, 1901, as amended.

54. Coal Mines Regulation Act, 1912, as amended.

55. Earthing of High Voltage Substations.
G. A. H. Swan & B. P. McRae, Journal I.E. Aust., March 66,
Vol. EE2 No. 1.

56. Code of Practice - Protective Earthing.
The Electricity Authority, N.S.W., 1965.