Electrical earthing in coal mines

National Coal Board - Headquarters Technical Department

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Preface

It has been recognised that electrical equipment and systems should be fitted with protection against dangerous earth leakage currents and the fundamental principles are well known. However, changes in the utilisation of electricity, changes in the design of equipment and the continuous development of improved methods of protection all contribute to a need to periodically update the information on available techniques.

The booklet is not intended to cover the whole subject but it collects together in one publication for easy reference the procedures thought to be best for application in British coal mines in most foreseeable situations.

J. Sharp
Deputy Chief Electrical Engineer

9th July 1985
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Chapter 1

Reasons for connections to earth

Electricity is the main source of energy used in coal mines, due mainly to the high efficiency and convenience by which it is passed along cables. It is a medium that must be used properly and with caution to enable safety to be maintained properly as open sparking, shock and fire are the main hazards which may be encountered when faults occur.

Correct connection of the enclosures of electrical apparatus to each other and to the mass of earth plays an important part in the containment of hazards and minimising disturbances due to electrical faults.

Control systems in mines are often of the digital form and of low amplitude. These can be affected by disturbance in the power distribution system as the earthing arrangements of both the power and control systems are normally connected to the main earth electrode at the surface of the mine and to all surface and underground plant.

Exposed conductive parts

The mass of the earth plays an unavoidable role in the working of all electrical systems, even if it is only that of a loose capacitance coupling. Also the majority of persons using electrical systems are at very nearly the same potential as the surrounding mass of earth so it is natural that this potential is chosen as the datum point for voltages on an electrical distribution system. All exposed conductive parts of electrical apparatus are therefore connected to earth to minimise any rise in potential of those parts above the surrounding area.

Distribution system insulated from earth

When a distribution system has no direct connection to earth it is said to be a fully insulated system; however two factors link the system to the potential of the earth mass, these are:

(i) the insulation resistance to earth; and
(ii) the system capacitance to earth.

The paralleling of the insulation resistance to earth of the various branches of a distribution system will bring the overall value of the insulation resistance down to the order of tens of thousands of ohms.

On a system with a good insulation value, the capacitance currents are the major components of leakage current (see Figure 1). If these currents are each represented by \( I_C \) with an applied voltage of \( V_P \), a leakage-to-frame fault of one phase conductor will short out the stray capacitance of that phase. Line voltage \( V_L \) will then be applied to the stray capacitances of the other two phases and charging currents of value \( \sqrt{3} I_C \) will flow in each phase.

In the first moments of a leakage-to-frame fault the current flowing external to the system will be the phasor sum \( I_f \) of the two currents \( \sqrt{3} I_C \) plus the collapsing capacitance current from the faulty phase. After which time the fault current settles down to a value \( I_f \) which is equal to three times the charging current.
Figure 1 Distribution system insulated from earth

The effect of switching the leakage-to-frame fault current is to create a considerable dc voltage between the sound phases and earth which, together with the ac voltage, increases the potential to earth of these phases to several times the normal voltage.

Low and high frequency oscillations, due to the natural capacitance and inductance of the distribution system, also often cause overvoltages.

All this overstressing of the insulation during the period increases the probability of a second leakage-to-frame fault. If a second leakage-to-frame fault occurs on one of the other phases during this time than a short-circuit fault current flows along the earth system conductors between the two faults and much damage is done to the system apparatus with consequential external dangers.

Monitoring systems exist for the detection of single leakage-to-frame faults but these are complex and generally shut down the whole distribution system. Monitoring arrangements which provide discrimination may be available in the future.

The stability of distribution systems isolated from earth is not too good and relies upon the effect of the stray capacitance in the system. Such systems are not favoured for use in UK coal mines because of the above problems.

**Distribution system connected to earth through a reactor**

This method (see Figure 2) is called resonant or Peterson Coil earthing and the value of the inductive reactance of the coil is chosen such that the capacitive component of a leakage-to-frame fault current is cancelled out by the inductive component of current produced by the reactor in the neutral-to-earth connection,
ideally creating zero earth fault current. For this condition to happen the inductive current should be equal to three times the charging current for the system.

This method is not suitable for coal mining electrical distribution systems because the stray capacitance of a mine system is always changing due to operational switching of circuits and apparatus and the more permanent change due to continuing extension of the system.

**Figure 2** Distribution system connected to earth through a reactor

**Distribution system connected directly to earth**

Damage can be done to the insulation of a distribution system, particularly under fault conditions, if the voltage on the system have no stable datum point. Therefore, it is common practice to connect the neutral point of star-connected generators or transformer windings to earth to provide this stable datum point (see Figure 3). The connection to earth should have a low resistance in order that the datum level is as representative of the mass of earth as possible.

This neutral connection also enables phase-to-earth faults to be effectively detected. A path for the fault currents to flow back to the neutral point is ensured by connecting all exposed metallic parts of apparatus to the earthed neutral point at the supply transformer.

**Distribution system connected to earth through a resistor**

When the neutral connected directly to earth the value of phase-to-earth fault current is limited only by the natural impedance of the transformer, cable cores and
armouring, etc, and the risk from all the potential hazards is high. If the current is to be controlled to a lower value then a balance has to be reached between:

(i) the stability of the system voltages;
(ii) the value of fault current; and
(iii) the sensitivity of the detection and tripping system to ensure that the fault is always isolated.

This is achieved by the fitting of a low resistor in the neutral-to-earth connection (see Figure 4).

Figure 3  Distribution system connected directly to earth

In the UK coal mines the majority of the distribution systems have a neutral resistor chosen for this duty to limit the phase-to-earth faults to the following maximum values:

- 3.3 kV system: 150 A;
- 6.6 kV system: 100 A.

The protection relays and associated apparatus should be chosen such that the prospective earth fault current shall be at least three times the tripping current, assuming zero fault impedance.
Expressed as a ratio:

\[
\frac{\text{Prospective earth fault current}}{\text{Tripping current}} \geq \frac{3}{1}
\]

This safety factor is necessary to ensure that enough current flows under two phase-to-earth fault connections to initiate the tripping of the controlling circuit breaker.

Putting a resistor in the neutral point to earth connection sacrifices some of the system stability when a fault occurs, since the neutral point voltage is not held at earth potential under earth fault conditions as stated on p.4. Figure 5 shows a phasor diagram for a typical three phase distribution system with a 12.7 ohm neutral resistor and 134 A earth fault current flowing from the R phase. The voltages to earth developed show that the line-to-earth insulation has to be adequate for the line-to-line voltage.

**Figure 4** Distribution system connected to earth through a resistor

**Protection against transformer interwinding faults**

The connection to earth of the neutral point of a three phase distribution transformer also provides a means of protecting the lower voltage secondary system from becoming charged to the level of the higher voltage primary system in the event of an interwinding fault in the transformer. The earth connection is seen as an earth fault by the higher voltage system which causes the protection to operate and isolate the fault.
Other systems

There are a variety of applications, especially single phase systems, where the earthing of the circuit has other safety functions.

Some single phase systems have the mid-voltage point connected to earth to halve the potential of either line to earth, particularly for circuits supplying portable tools or lighting. Other circuits used for control have one line connected to earth to protect against malfunction of the circuit when earth faults occur.

Where intrinsically safe circuits can be earthed the point of earthing should be determined at the design stage. This is dependent on the operational safety of the circuit or upon such factors as safety in hazardous atmospheres and the effects of interference from other circuits.

**Figure 5** Typical phasor diagram for a three phase distribution system under earth fault conditions

NR - R phase voltage
NE - Potential drop across the neutral resistor (1714 V)
ER - Potential drop across the remainder of the fault current path (220 V)
EB - Potential of line B to earth (3220 V)
EY - Potential of line Y to earth (3072 V)
Chapter 2

Earthing Arrangements

Revised terms for earthing arrangements

Over the last few years the terms used for the various parts of the earthing arrangements for an electrical distribution system have been changing. The modern terms are given in literature by the International Electrotechnical Commission (IEC)\(^1\) and the Institution of Electrical Engineers (IEE)\(^2\).

Figure 6 illustrates the main changes where:

- the actual connection to earth, formerly called the earth plate, is now called the **earth electrode**;
- the busbar, normally at the surface substation, which is the collecting point for the mine earthing system conductors is the **main earth terminal**;
- the connection between the main earth terminal and the earth electrode is the **earthing conductor**;
- cores used for earthing purposes in cables, armouring and screens of cables and external conductors connecting the earthing terminals of switchgear are **circuit protective conductors** usually shortened to **PE conductors**;
- the connecting conductors (where necessary) between electrical apparatus and the adjacent metal enclosures and structures are **equipotential bonding conductors**.

A practical mine example will not necessarily follow exactly that portrayed in Figure 6 but the general principles should be adopted.

The installation and testing of earth electrodes

The installation and maintenance at a mine surface of an efficient connection of the earthing system with the main body of earth is required and a resistance value of 2 ohm is generally accepted as reasonable and attainable.

Principal types of earth electrode

Coke electrode

A coke electrode usually takes the form of metal plates or pipes, or a large scrap casting, placed in a pit and surrounded by coke breeze. It is the commonest type employed at coal mines and has the advantages of very long life and the ability to dissipate heavy fault currents.

In the simplest form a pit is dug, about 2 m or 2.75 m (6ft or 9ft) deep, and coke breeze laid at the bottom to a depth of 0.3 m (1 ft). Two, three or more cast iron pipes, 0.15 m or 0.23 m (6in or 9in) diameter by 2 m or 2.75 m (6ft or 9ft) long, are placed side by side standing upright upon the bed of coke, and the pit is then filled with coke breeze (well rammed) up to ground level. The top flanges of the pipes, which will then project 0.3 m (1 ft) above the coke, are bonded together using copper or brass strip and brass bolts and nuts, and the earthing conductors are attached to this bonding. A low brick wall or concrete kerb may, with advantage, surround the perimeter of the pit but should not protrude into the coke breeze.

*Note:* The effective resistance of any earth electrode depends upon two factors only, namely, the resistance of the contact between the electrode and the soil and the resistivity of the ground beyond the electrode.
Figure 6  The main components of underground earthing system

Values normally accepted for the resistivity of various soils are given in Table 1.

Table 1  Resistivity values of soil

<table>
<thead>
<tr>
<th>Type of Soil</th>
<th>Resistivity in ohm-cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay, loam</td>
<td>2k - 6k</td>
</tr>
<tr>
<td>Sandy clay, gravel, chalk</td>
<td>6k - 20k</td>
</tr>
<tr>
<td>Peat</td>
<td>15k - 30k</td>
</tr>
<tr>
<td>Sand</td>
<td>25k - 50k</td>
</tr>
<tr>
<td>Rock</td>
<td>Up to 1M</td>
</tr>
</tbody>
</table>
Since the resistivity of coke breeze, when well rammed, is of the order of 40 ohm-cm and the resistance of contact between the metal electrodes and the coke will be negligible, it is clear that the important factor is the contact resistance between the coke and the soil, the function of the coke being to increase the area of contact.

From the results obtained by the British Electrical and Allied Industries Research Association and other investigators, the resistance of a coke electrode is given approximately by the formula:

\[ R^2 = \frac{13.4}{A} \times \frac{\rho}{1000} \]

Where

\( R \) = Total resistance of the electrode in ohms
\( \rho \) = Resistivity of the soil in ohm-cm
\( A \) = Total area of contact between coke and soil in square metres

The total area required for a resistance of 2 ohm given a soil resistivity of 10 750 ohm-cm is:

\[
A = \frac{13.4}{R^2} \times \frac{\rho}{1000}
\]

\[
= \frac{13.4}{4} \times 10.75
\]

\[
= 36 \text{ m}^2
\]

This would require a pit 2.25 m x 2.25 m x 3 m deep, containing approximately 7.5 tonne of coke breeze. It is necessary, however, to provide at least two earth electrodes, so that tests may be made without disconnection of the earthing system. Two electrodes, when connected in parallel, may have a resistance of 4 ohm each, which reduces the area required of each pit to 9 m2 or say 1 m x 1 m x 2 m, each containing about 1 tonne of coke breeze. It would be wise, however, to make each pit 2.5 m deep, giving 12.5 m2 area.

**Rod electrode**

The use of copper or steel rods, 12 mm to 25 mm diameter and 3 m or more in length, driven into the soil, has increased greatly of recent years and is now standard practice for power stations and substations of the UK electrical supply authorities.

Rods have the advantage or requiring no excavation and consequently are cheaper to install. They are, however, less permanent, being more susceptible to corrosion than the coke electrode, and are therefore less satisfactory for installation in made ground containing ashes. Where the sub-soil consists of gravel or sand with a stratum of clay beneath it, it is an advantage to be able to drive rods through the upper layers into the region of lower resistivity.

The resistance of a single rod is given by the formula:
\[
R = \frac{p}{270L} \log \frac{4000L}{d}
\]

Where \( p \) = soil resistivity, in ohm-cm
\( L \) = length of rod, in metres
\( d \) = diameter of rod, in millimetres

From this formula, a 25 mm rod, 3 m long, in soil having a resistivity of 10 000 ohm-cm will have a resistance of 33 ohm, and 17 such rods will be needed to give the required resistance of 2 ohm. Before determining the actual number, however, it is advisable to drive a test rod as deep as possible on the site, since the soil resistivity may be found to be lower than the estimated value.

When a number of rods are combined to form an earth electrode, they should be so spaced that the distance between any two rods is at least equal to twice the length of the rod. If this is not done the resistance areas will overlap; and two rods in parallel will not provide half the resistance of a single rod. So spaced, the 17 rods will occupy a ground area of about 30 m x 12 m. If the spacing were reduced to equal the length of a rod, at least 40 rods would be needed.

For driving the rods a light electric or compressed air hammer is generally employed. If driven by hand, a 2 kg hammer can be used; use of a heavier hammer might result in bending the rods or deforming the upper end.

**Strip electrode**

It will usually be found that the upper layers of the sub-soil possess a higher resistivity than those lying beneath them. There are cases, however, where there is a shallow layer of sub-soil over rock or sand, and in these circumstances it may be difficult to obtain the necessary low resistance with an electrode consisting of coke or rods.

Bare copper strip or stranded copper conductors may then be laid in the ground at a depth of about 0.5 m in either one continuous length or in separate lengths radiating from a central earthing point.

The resistance will then be obtained from the formulas:

for strip

\[
R = \frac{p}{275L} \log \frac{2000L^2}{wt}
\]

for stranded conductor

\[
R = \frac{p}{275L} \log \frac{1000L^2}{dt}
\]

Where \( p \) = resistivity of soil, in ohm-cm
\( L \) = length of electrode, in metres
\( t \) = depth of burial, in metres
\( w \) = width of strip, in millimetres
\( d \) = diameter of stranded conductor, in millimetres
For a resistance of 2 ohm in soil of 10000 ohm-cm resistivity, a length of about 120 m will be required, whether the electrode consists of strip or stranded conductor. Strip electrodes should be about 25 mm x 3 mm and stranded conductors not less than 490 mm$^2$ section. Tinned copper will better resist corrosion, especially in made ground.

Strip electrodes are more subject to variation through seasonal changes in the dampness of the soil, and the site chosen should be naturally and permanently moist.

If the strip is surrounded by coke breeze to a distance of 0.25 m in every direction its resistance will be approximately halved.

**Plate electrode**

The use of plates of cast iron or copper, buried directly in the ground, is rapidly dying out. A 1 m x 1 m plate, buried with its centre 2 m below the surface of the ground in soil of 10 000 ohm-cm resistivity will have a resistance of about 27 ohm compared with 34 ohm for a single 25 mm rod, 3 m long.

**Buried water mains**

A line of cast iron or steel piping, constantly full of water, may be used as a subsidiary earth but should never be relied upon as the main earth electrode. Pipe jointing materials may act as insulators between sections and, if the piping is not under the control of the colliery, the modern technique of using pipes of asbestos cement or plastic materials for repair may render it useless as an earthing medium.

**Testing**

Every earth electrode is probably passing very small currents continuously into the surrounding soil and electrolytic action will certainly take place if the soil conditions are appropriate. It is therefore important that the resistance of the earth plate should be checked periodically.

The simplest method of testing, where two or more separate electrodes are provided, is to isolate one electrode from the earthing system and connect a source of direct current (such as a car battery) in series with an ammeter, between this and another electrode, so as to pass a current through the ground between them. The source of power should then be reversed and a second reading taken to eliminate stray earth currents due to polarisation. A simple testing panel comprising ammeter, voltmeter and double pole reversing switch will enable the test to be carried out with the least delay.

Where only one electrode, such as a group of rods or strips, is provided, or where it is inconvenient to separate the electrodes, an instrument known as the Earth Tester or Earth Testing Ohmmeter may be used. In making the test a spike (a steel spike, 12 mm diameter and 1 m long is recommended) is driven into the ground at a suitable distance from the electrode under test and a second spike driven halfway between these two. The first spike is connected to the current terminal of the instrument and the second spike to the potential terminal, while the electrode is connected to the earth terminal. On turning the handle of the instrument the resistance of the electrode may be read in ohms.

If the instrument is provided with two potential terminals it may be used to determine the resistivity of the soil. Four spikes are driven into the ground in a row,
spaced x centimetres apart. The end spikes are connected to the earth and current terminals and the intermediate one to the two potential terminals. The resistivity of the soil is then given by:

$$p = 2\pi x R$$

Where
- $p$ = resistivity of the soil in ohm-cm
- $x$ = the spacing of the spikes, in cm
- $R$ = the reading of the instrument, in ohms

**Equipotential bonding at the main substation**

Electricity for use at a coal mine is generally purchased from a Supply Authority and the main surface substation can be regarded as the source of electricity. It is also an important interface between the supply authority and mine distribution systems.

Wherever possible all exposed conductive parts in the same substation whether colliery, or authority, owned should be bonded together and connected to the mine earth electrode (see Figure 7). Copper cables are normally used for this purpose but other materials, such as galvanised steel, may be used.

![Figure 7](image)

**Earthing of the metal sheaths of single core cables**

Often large single core cables are used to connect a supply transformer to its associated switchgear. If these cables have lead sheaths then an ac voltage is induced into the sheath when an ac current flows in the core. Generally the systems are three phase and the single core cables can be installed in a trefoil group for the major part of the route, opening out at the end to enable the connections to be made off.

The necessary earthing of such cable arrangements brings two problems:

(a) earthing and bonding at both ends introduces cross bonds between the sheaths which allows circulating current to pass through the sheaths giving rise to additional losses and heating;
(b) if the cables are earthed and bonded at one end only and so installed that the sheaths are otherwise insulated from each other and earth then no sheath...
currents can flow, but dangerous voltages may appear at the unearthed end of the sheath under fault conditions.

To maintain safety the sheath circulating currents should be included when designing earthing system. The size of the sheath currents increases with the spacing. It is therefore necessary to erect the three cables of a three phase group as close together as possible.

At the end of the cable route the trefoil groups have generally to be widened out to suit the terminal arrangements. If the ends are part of a long set of cables in close trefoil formation the resistance of the sheath will be sufficiently high to limit the sheath currents. This arrangement of bonding at both ends requires that the sheaths of the cables in a trefoil group be insulated from each other in wood or bushed metal cleats in order to make the circulating currents traverse the whole length of the cables. In dry situations the normal servings may form a sufficient insulation.

To earth at or near both ends of a short route it is necessary to separate the end effects from the main run by making the earth connection and the bond between the sheaths at the point where the trefoil is opened out. No further bonding is permissible at the ends, but the main route can be earthed and bonded at intermediate positions. Bare lead-sheathed cables may thus be erected in metal uninsulated cleats for the main run and the ends erected in insulated cleats or covered with an adequate serving if erected in metal cleats. The terminal equipment or cable glands must also be insulated from earth.

If the heating effect of the sheath currents cannot be accepted, the cables and terminations must be erected insulated from each other and from ground and be earthed and bonded at a single point which may be at any position along the route. An earth at the end will be suitable if the route is short, otherwise the earth bond should be made at the mid-point. In special cases the sheath can be sectioned by insulated boxes in order to keep down the sheath voltage.

Single-bonded cables should only be installed where they are out of unauthorised access when alive.

**Earth fault current paths**

The armourings of cables (PE conductors) are designed to carry earth fault currents back to the transformer and minimise the potential rise on the metal enclosures (exposed conductive parts) of the faulty apparatus.

Depending upon the site conditions upon which the faulty apparatus is erected (such as the conductance of the strata, etc) a small proportion of the earth fault current may find its way back to the earth electrode at the surface by way of the earth mass. Although the resistance of the earth electrode to the earth mass is kept at a low value so as not to inhibit the current flow to earth the size of these earth currents is not predictable. For underground mining operations reliance should only be placed upon the protective conductors which have a known value of conductance.

**Conductance of protective conductors**

The recommended minimum conductance for external protective conductors which are not part of a cable are given in Table 2.
**Table 2** Minimum conductance for external protective conductors

<table>
<thead>
<tr>
<th>Largest cross-sectional area of power conductor (mm²)</th>
<th>Minimum conductance of protective conductor</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 16</td>
<td>equal to power conductor</td>
</tr>
<tr>
<td>&gt;16 to = 35</td>
<td>equal to power conductor of 16 mm²</td>
</tr>
<tr>
<td>&gt; 35</td>
<td>equal to half power conductor</td>
</tr>
</tbody>
</table>

**Equipotential bonding**

Equipotential bonding is connecting together, electrically, all exposed conductive parts of electrical apparatus. In situations such as surface methane extraction plant or underground where earth currents cause undesirable potential differences in the strata it may also be necessary to connect together the conductive parts of machinery, pipework, support girders, etc, within a sphere of operations. This will ensure that they are all at a common potential under most practical conditions of service. Thus the potential which may appear across two parts in the same locality is virtually zero, even though the potential of the whole assembly may be elevated above some datum point. The minimum cross-sectional area of all equipotential bonding conductors should be 4 mm².

**Combined protective and equipotential bonding conductors**

It is often the practice in coal mines to combine the functions of the protective and equipotential bonding conductors (see Figure 8) especially where conductors are looped across the external earth terminals of switchgear and gate end boxes. Any rules or recommendations for these conductors (for example conductance) should be on the basis of the protective function.

![Figure 8 Protective and equipotential bonding](Image)
Chapter 3

Connecting transformers in parallel

Careful consideration should be given to the paths and values of earth fault current relative to the protective devices when connecting distribution transformers in parallel.

When the neutral points of the transformers’ secondary windings are connected directly to earth the connection of transformers or cables in parallel has a major effect on the value of the earth fault current. An earth fault near two transformers can be virtually twice the value for one transformer. For an earth fault occurring at the extremity of a long radial feeder the decrease in total impedance due to paralleling the two transformers may not be very great and the supply end protection will not see much more than half the value for one transformer.

Neutral-to-earth impedances

When transformers have neutral-to-earth impedances, the connecting of the transformers in parallel does not in itself have a significant effect on the value of earth fault current because the neutral impedances are the dominant factor. Therefore, the configuration of the neutral impedances is of considerable importance and has an effect upon the earth fault current value.

Figure 9 illustrates two methods of connecting the neutral point impedances of two distribution transformers to earth.

In a single neutral impedance system the total earth fault current is kept fairly constant due to the value of the neutral impedance, whether the transformers are connected in parallel or not. However, when the transformers are connected in parallel the protection for each transformer sees only half the value of earth fault current that it would see if the transformers were not connected in parallel.

When the transformers have individual neutral impedances, a parallel connection of the transformers parallels the effect of the neutral impedances and twice the unit value of earth fault current will flow in the external circuit. The supply end protection will, in this case, see the value of earth fault current which would flow if the transformers were not connected in parallel.

Table 3 brings the facts together assuming that unit earth fault current flows from one transformer and one neutral impedance system.

Voltage potential of neutral point to earth

When a transformer has a neutral impedance, there is no voltage drop across the neutral impedance whilst there is no earth fault current flowing. However, when an earth fault occurs, the voltage drop across the neutral impedance (see Figure 5 on page 9) can be nearly as much as phase volts and the potential of the neutral point, and its connections, will be displaced above by this value of voltage.
If two transformers are not connected in parallel and an earth fault occurs on the system associated with one of them, different effects will be seen on the two systems:

(a) Single neutral impedance
A voltage across the impedance will affect both transformers. Therefore both switches S1 and S2 (see Figure 9a) should be put into the neutral point connections to enable each transformer to be maintained safely. If a transformer is energised then the potential of switches S1 and S2 may be raised above that of earth and it is, therefore, important that no work be conducted on S1 and S2 and associated connections unless the whole of the distribution system, connected to a particular neutral impedance, is completely de-energised.

It should be noted that, where switches are used in the transformer neutral point to earth connections, these switches should be properly interlocked with the primary and secondary switches controlling the transformer. This is necessary to ensure that the neutral is connected to earth before the transformer is energised and the transformer is de-energised before the neutral is disconnected.

(b) Individual neutral impedances
A voltage across one impedance due to an earth fault associated with one transformer will not adversely affect the other transformer. There is, therefore, no need to disconnect the transformer neutrals from the impedances and earth.
connections. It should be remembered that a neutral point and its connections to the neutral impedance, while normally at earth potential, will be raised to a quite high potential above earth in the event of an earth fault. For this reason a neutral impedance and its connected circuits should be regarded as live until the associated transformer has been isolated.
Chapter 4

Three phase and single phase systems

In three phase and neutral systems the 415 V phase-to-phase voltage is often used for supplying motors, etc, and the associated 240 V phase-to-neutral voltage will be used for lighting and office machines (see Figure 10). It is good practice to keep the functions of the protective and neutral conductors separate although both are connected to the earthed neutral point of the system transformer. All such systems have solidly earthed neutral points and the Electricity Supply Regulations, 1937 forbids any impedance being put in the connection of the neutral point to earth for public supply systems.

Fuses in the neutral conductors are not normally allowed, although links may be used. Any circuit breaker in the circuit which interrupts the neutral conductor shall also interrupt the line conductor at the same time.

A special case is the connection to an intrinsically safe power supply through a double wound transformer with an earthed screen between the windings. It is considered necessary that in order for the IS supply to remain safe under all conditions it is better to fuse both line and neutral conductors to the transformer. No other apparatus should be connected to the load side of the fuses.

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Figure 10 Three phase and neutral distribution

This is because there is a time factor involved in the fault-withstand capabilities of the safety screen between the two windings of the transformer and any primary winding-to-screen fault will be isolated before the secondary winding is affected.
Fusing both conductors to the transformer caters for certain neutral conductor faults and inadvertent reversal of the two incoming supply conductors to the transformer.

**Lighting circuits**

Lighting circuits are generally supplied from the secondary winding of a transformer and it is usual to connect the mid-voltage point to earth. This is mainly to limit the circuit voltage to earth thereby reducing the danger of electric shock but it also allows the limiting of prospective earth fault currents, their detection and isolation by earth leakage relays (ELR in Figure II).

**Control circuits**

If a control circuit with an earth leakage relay and a set of contacts is not earthed then earth faults around the contacts are likely to cause the relay to operate.

Should earth faults be present around the contacts then the mid-voltage point earth connection on the circuit is likely to cause the relay to hold-in on half voltage after opening of the contacts.

![Figure 11 Centre point earth fault detection](image1)

A connection to earth at the transformer output terminal nearest to the relay will allow the fuse to blow and the circuit will fail to safety should earth faults be present around the contacts (see Figure 12).

![Figure 12 Control circuit protection against malfunction due to earth faults](image2)
Chapter 5

Earthing of mining apparatus

The recommended earthing arrangements for non-electrical apparatus and particular electrical systems and apparatus are discussed in this chapter.

Non-metallic enclosures

Non-metallic enclosures of power apparatus designed specially for mining applications (see, for example, Figure 13) should, and in general will, incorporate a permanent bonding conductor between all cable glands and any exposed metal parts which might become charged to a dangerous voltage. Care should, however, be exercised with other commercially available products where attention to bonding may be left to the user.

Figure 13  PE bonding in non-metallic light fitting

Earthing of non-electrical apparatus

Static electricity charges can accumulate on insulating materials due to friction, even by the movement of air (especially if it contains dust particles). This presents a hazard when the equipment is installed in a part of the mine where a potentially explosive atmosphere may exist. With electrical apparatus this danger is generally minimised at the design stage, when this aspect will have been considered, but awareness of the problem can help when on-site assembly of non-electrical apparatus is taking place.

If a metal part is insulated from earth it acts as one plate of a capacitor and hence, if it acquires a charge, energy is available for discharge sparking. Safety can be improved by connecting such metal parts to earth. A high resistance connection to earth is sufficient to safely discharge static electricity as long as the connection is secure (see Figure 14). Where convenient the metallic outer coverings of the electrical supply system provide a particularly effective earth for this purpose.

Figure 14  Method of discharging static electricity
Earthing of sampling tube bundle cables

If the armourings of tube bundle cables are connected to the earthing system of the mine they will, in the event of an electrical distribution system earth fault, carry part of the fault current finding its way back to the neutral point of the supply transformer.

In the early days of the use of tube bundle cables it was considered advisable that the tube bundle cable installations be kept insulated from the mine distribution cables, control and communications systems and earth, in order to keep electric currents separate from tubes which may contain firedamp.

Experience has shown that it is very difficult to ensure that a tube bundle system using armour glands and junction boxes is effectively insulated from earth and the electrical systems in the mine. Partial failure of the insulation may lead to open sparking in the event of an electrical system earth fault, which is worse than carrying fault current in the properly connected armourings of a tube bundle system.

It is therefore considered prudent and safest to connect the armourings, junction boxes and associated apparatus of tube bundle systems to the mine earthing system just as if it was part of the electrical system.

Earthing of intrinsically safe apparatus and systems

There is no general rule appertaining to the connection of intrinsically safe circuits to earth but the specific requirements in each case will be found in the certification documents.

For many years the connecting of signalling systems to earth was prohibited. This was based on the fact that even a partial earth fault on the opposite line to the earthed line could prevent the signal bell from ringing thereby losing haulage control. The connection to earth of modern signalling systems is now permitted providing that the system is designed correctly.

Nowadays the connection of intrinsically safe systems to earth is used to improve operational safety and, in some cases, to ensure the intrinsic safety of the systems (see Figure 15). No circuit should be connected to earth at more than one point. If the certification documents permit a circuit to be connected to earth, they will define how such connections are to be made.

![Figure 15 Deliberate earthing of IS circuits](image-url)

Communication and control circuits

It is common practice to use wire armoured cables for communication and control circuits to withstand the rigours of the mining environment. These cables are normally connected to apparatus which is already connected to the power earthing system. Figure 16 shows the outer metallic enclosures of a data transmission highway connected in parallel with the protective conductors of the power distribution system as a typical example.
If the armourings of a data transmission cable are correctly made off then any rise in potential of the exposed parts of the apparatus above that of earth due to an earth fault on the distribution system will cause current to flow in the armourings of both the power and data transmission cable and no danger arises.

If the data transmission cable armourings are not made off correctly then voltage will appear across the gaps in the armouring and cable entry assemblies under conditions of an earth fault on the associated distribution system and there is a distinct danger of open sparking.

![Figure 16: Cable connections for power and data transmission systems](image)

Figure 16: Cable connections for power and data transmission systems

It is considered highly impracticable to insulate a data transmission system from the associated power distribution system and it is far safer to accept the earth fault currents in the armourings of the data transmission cables when under properly controlled conditions. Although earth fault currents may flow in the armourings of cables associated with intrinsically safe circuits the circuits themselves will not be adversely affected.

**Segregation within large intrinsically safe networks**

Some data transmission systems have a common OV reference conductor which is connected to earth at the surface of the mine and extends to all outstations (see Figure 17). Although these systems were originally designed to accept signals from voltage-free relay contacts, analogue circuits are now often connected to them.

The transmission of analogue signals of the 0.4 to 2 volts form require a galvanic connection between the external transducers and the outstation circuitry. This extends the OV reference conductor beyond the outstation and thus increases the probability of inadvertent earth faults. Such earth faults can both prevent the operation of the transmission system and cause erroneous analogue signals.

Various devices are in use which completely, or partly, segregate the external analogue transducers from the outstation circuits. However the most effective method of combating the problem is an awareness of the requirement of one connection to earth at the surface only and a high standard of installation and maintenance to preserve the insulation of the transmission system.
Modern data transmission systems make use of isolating transformers or opto-coupling devices which segregate the various sections of the system. Therefore earth faults at outstations do not affect the rest of the transmission system. The outstation, associated power supplies and transducers should have only one connection to earth to limit the effect of earth faults. This is normally provided at the outstation (see Figure 18).

DC power supplies to BS 6182⁴ provide for an earth connection but this should be linked in or out, as required by the certification documents for the intrinsically safe systems in which the power supply is used. The output circuits of transducers, designed to meet the requirements of BS 5754⁵, have no connection to earth and this may require the earthing provision at the dc power supply to be left unconnected.

Earth faults on a modern data transmission system do not affect the intrinsic safety and the whole network is normally contained within outer metallic coverings connected to earth which protects against external voltages being impressed on the system.
Chapter 6

Interference

The performance of a data transmission system can be affected by interference, particularly if the exposed conductive parts and the circuits of the data transmission system are not earthed correctly.

The three types of interference which may affect a system are described below:

(a) Earth loops
For the purpose of safety it is good practice to connect all apparatus such as cubicles, desks, racks, etc, in a control room to a common busbar in the room and then to connect this busbar directly to the earth electrode for the mine. In any considerations of the earthing system this direct connection should not be the protective conductor for other apparatus.

The bus bar in the control room also provides a convenient earthing point for the data transmission system and for the zener barriers which protect the underground circuits from the effects of mains voltage under fault conditions.

Commoning of the connections to earth is likely to cause an elevation of the electronic circuit voltage during the period of a fault to earth in the power circuit. Figure 19 illustrates the increase in voltage to earth of a data transmission system due to the part of the fault current which flows in the common impedance AB.

The voltage V can be reduced by:

(i) using large cross-section area copper connections from the mine earth electrode to the control room busbar; or
(ii) using a separate connection from point B to the mine earth electrode.

Method (i) only reduces the effect while with method (ii) the effect may show itself through inductive or capacitive coupling in the cubicle because the cubicle may have a different voltage datum point to the circuit. It should be noted that on 240 V supply systems which have simple fuse protection, earth faults on the neutral conductor are likely to remain undetected for some time but will cause currents to flow in the exposed conductive parts causing voltage drops and a likely elevation of the voltage datum for the data transmission system. Core balance earth fault detection is the best method of detecting this type of fault.

(b) Capacitive coupling
Capacitive coupling can arise between different circuits in a multicore cable or between those circuits and a screen or armouring. The effect can be minimised by employing balanced transmission lines (see Figure 20) particularly if the impedance of the circuit is not too high.

Balancing is achieved by arranging the layout of the lines so that the capacitive coupling effect is cancelled out and each line must have the same impedance to earth. If the voltage on an enclosing screen or armouring is suddenly increased the internal conductors will attempt to rise through the same voltage value. A coupling transformer is only likely to transmit this transient voltage by capacitance coupling.
Inductive coupling can arise between different circuits in a multicore cable or between those circuits and a screen or armouring. This effect is minimised by using adjacent conductors, preferably a twisted pair (see Figure 21), for the same circuit. Circuits which involve more than two conductors cannot fully comply with this recommendation and it is necessary to arrange the conductors so that those most vulnerable to interference are close to the OV reference conductor.

The armouring of data transmission cables will carry current while a power circuit fault exists and a voltage will be generated in the conductors of the cable but in the same sense in the two conductors of a pair, so that the induced voltage in a loop circuit is almost cancelled out (see Figures 21 and 22).
If the protective conductor of the cable is broken the voltage on the cable armouring with respect to earth will follow the potential on the power system protective conductors to which the cable is connected and thus may present a transient to connected circuits.

Figure 22 Voltage elevation on conductors due to voltage elevation on armours

Typical $V$ for voltage elevation

- $V = 100$ V
- for 100 K ohm circuit = 68 V
- for 10 K ohm circuit = 12 V
Chapter 7

Mobile plant and welding sets

Mobile plant

The use of mobile or transportable plant at a coal mine brings unique problems as such plant is normally powered from an on-board or closely associated generator, has rubber-tyred wheels and cannot be connected to the mine earthing system easily.

All on-board enclosures of electrical and associated apparatus, including the frame, cabin and other mechanical features which may become live, should be connected together by means of protective and equipotential conductors as necessary. The conductance of these conductors should follow the recommendations given on pages 16 and 17.

Where the utilisation section is separate from the generation section, for example some arrangements of beanpole lighting, particular attention should be given to the continuity of the bonding system between the two sections.

The distribution systems associated with such items of plant are very small and no stability problems are expected under fault conditions which would give rise to high voltage stressing of the insulation. It is therefore considered that whilst the connecting of the plant bonding system to the mass of earth would do no harm it does not provide a lot of benefit.

Welding sets

The majority of welding sets in use at coal mines are of the ac type using a double wound transformer and an automatic open circuit voltage reducer (see Figure 23).

It is essential that the transformer tank and control handles are effectively connected to the mine earthing system. The transformer secondary winding should not be directly connected to earth at the tank but should be connected to earth through the welding return lead and an earth lead. The earth lead should be connected at one end to the metal being welded and at the other to the earth terminal at the transformer tank.

![Figure 23 Earthing of welding circuit and work](image)

This ensures not only that the earth lead and chance earth paths do not carry the welding current back to the transformer but also that the work metal is virtually at the same potential as surrounding metalwork and the risk of shock voltage from work to earth is greatly reduced,
Chapter 8

Lightning conductors

Guidance on lightning protection is given in the Code of Practice, BS 6651\(^6\), published by the British Standards Institution. It should be noted that all-metal structures are usually self-protecting if they have an acceptable conductance to earth.

Systems employing radioactive materials are not considered to be any more effective than conventional systems and are not recommended.
Appendix

Regulations relating to earthing

For ease of reference the relevant existing Regulations are given below.

Extracts from the Coal and Other Mines (Electricity) Regulations

Regulation 13 of the Coal and Other Mines (Electricity) Regulations states:

13(1) There shall be connected to earth at the surface of the mine in such manner as will ensure immediate electrical discharge without danger:

(a) every metallic covering of any cable;

(b) the outer conductor of every concentric cable;

(c) every metallic part of any covering or container of, or mounting for, any other electrical apparatus; and

(d) any handle for the operation of any electrical apparatus.

(2) Without prejudice to the generality of the last preceding paragraph, every earthing conductor installed for the purposes thereof shall have a conductivity throughout (including any joint) not less than half that of the conductor having the greatest current carrying capacity in relation to which it is provided and shall have a cross-sectional area not less than 14 square millimetres:

Provided that

(a) in relation to a flexible cable by which electricity is supplied at a voltage not exceeding one hundred and twenty-five to portable apparatus, nothing in the preceding provisions of this paragraph shall require the earthing conductor to have a cross-sectional area greater than 6 square millimetres; and

(b) in relation to a flexible cable by which electricity is supplied to portable apparatus of capacity not exceeding three kilowatts at the surface of a mine, being a cable comprising an earthing conductor, nothing in the preceding provisions of this paragraph shall require the earthing conductor to have a cross-sectional area greater than that of any one of the other conductors in that cable.

(3) Subject to the preceding provisions of this regulation and to the provisions of regulation fifteen, the metallic covering of any cable may be used as an earthing conductor.

(4) No switch or circuit breaker shall be placed in any earthing conductor.

(5) Anything below ground in a mine that these regulations require to be connected to earth and when connected to earth any neutral point, mid-voltage point or pole of any electrical system below ground in a mine shall all be connected at one and the same place to the earthing system of the mine and both that place and that earthing system shall be at the surface of the mine.

(6) Nothing in this regulation shall apply to

1 Includes ‘fuse’: See definition in Regulation 26(1)
(a) any lamp holder which is efficiently protected by a covering made of fire resisting material which is either insulated or earthed;

(b) any hand-held tool which is double insulated to a standard which complies with a specification approved for the purpose of this regulation by the HSE;

(c) any portable apparatus in any circuit in which the voltage does not exceed 50 direct current or 30 to earth alternating current; or

(d) any apparatus in any circuit in which the voltage does not exceed 250 direct current or 125 alternating current, other than portable apparatus.

Extracts from the Coal and Other Mines (Safety-Lamps and Lighting) Regulations

18(2) Electricity exceeding 250 volts shall not be applied to any such lights, and where the system is single phase alternating current or direct current, the mid-voltage point shall be connected to earth, and where it is polyphase alternating current, the neutral point shall be connected to earth; but -

(a) no automatic circuit breaker or fuse shall be used in any such connection as is described in this paragraph; and

(b) the requirements specified in this paragraph shall not apply to indicator lights which are accessories to switchgear.

18A(3) Any lights or apparatus certified or approved under this Regulation as being suitable for use in such an area as is specified in paragraph (I) hereof may only be used if -

(a) the power supply to such lights or apparatus does not exceed 125 volts;

(b) the only power supply to the system is either -

(i) single phase alternating current or direct current with the mid-voltage point connected to earth, or

(ii) polyphase alternating current with the neutral point connected to earth, and no automatic circuit breaker or fuse is used in any such connection to earth (except that the requirements specified in this sub-paragraph shall not apply to indicator lights which are accessories to switchgear);

(c) the maximum prospective leakage current to earth of the system does not exceed one ampere;

(d) effective means are provided for automatically cutting off the supply of electricity if the leakage current to earth of the system exceeds one third of its maximum prospective leakage current to earth;

(e) every cable supplying such lights is protected throughout by a suitable metallic covering, containing in any given place all the conductors forming part of the system in that place, and having a conductance throughout of at least one half carrying capacity enclosed thereby; and of the conductor having the greatest current -

(f) every flexible cable -
(i) has each of its cores enclosed in a screen of wires which is an earthing conductor and has a conductance of at least one quarter of the core it encloses; and

(ii) is connected to any other electrical apparatus by means of a properly constructed connector which has suitable provision for connecting to earth the screens of wires enclosing the cores.
References

1 INTERNATIONAL ELECTROTECHNICAL COMMISSION, 364-4-41 (1977)
   Chapter 41.

2 THE INSTITUTION OF ELECTRICAL ENGINEERS

3 ELECTRICITY COMMISSION

   ‘Intrinsically safe power supplies for use in coal mines: specification for dc
   power supplies’. London.

5 BRITISH STANDARDS INSTITUTION, BS 5754: 1980.
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6 BRITISH STANDARDS INSTITUTION, BS 6651: 1986.

7 HEALTH AND SAFETY EXECUTIVE, Coal and Other Mines (Electricity)
   Regulations 1956.
   ‘The law relating to safety and health in mines and quarries’. HMSO, London,
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